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It is unnecessary here to say anything on the merits of this work, already so well established as the most popular and instructive manual of science in the English language.

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H. G. B.

June, 1855.

PREFACE

TO THE ORIGINAL EDITION.

THE Author of this volume feels himself extremely happy in the opportunity which this publication affords him of acknowledging the obligations he is under to the authors of "Practical Education," for the pleasure and instruction which he has derived from that valuable work. To this he is indebted for the idea of writing on the subject of Natural Philosophy for the use of children. How far his plan corresponds with that suggested by Mr. Edgeworth, in his chapter on Mechanics, must be left with a candid public to decide.

The Author conceives, at least, he shall be justified in asserting, that no introduction to natural and experimental philosophy has been attempted in a method so familiar and easy as that which he now offers to the public—none which appears to him so properly adapted to the capacities of young people of ten or eleven years of age; a period of life which, from the Author's own experience, he is confident is by no means too early to induce in children habits of scientific reasoning. In this opinion he is sanctioned by the authority of Mr. Edgeworth. "Parents," says he, "are anxious that children should be conversant with mechanics, and with what are called the mechanical powers. Certainly no species of knowledge is better suited to the taste and capacity of youth, and yet it seldom forms a part of early instruction. Every body talks of the lever, the wedge, and the pulley, but most people perceive, that the notions which they have of their

respective uses are unsatisfactory and indistinct; and many endeavour, at a late period of life, to acquire a scientific and exact knowledge of the effects that are produced by implements which are in everybody's hands, or that are absolutely necessary in the daily occupations of mankind."

The Author trusts that the whole work will be found a complete compendium of natural and experimental philosophy, not only adapted to the understandings of young people, but well calculated also to convey that kind of familiar instruction which is absolutely necessary, before a person can attend public lectures in these branches of science with advantage. "If," says Mr. Edgeworth, speaking on this subject, "the lecturer does not communicate much of that knowledge which he endeavours to explain, it is not to be attributed either to his want of skill or to the insufficiency of his apparatus, but to the novelty of the terms which he is obliged to use. Ignorance of the language in which any science is taught is an insuperable bar to its being suddenly acquired: besides a precise knowledge of the meaning of terms, we must have an instantaneous idea excited in our minds whenever they are repeated: and, as this can be acquired only by practice, it is impossible that philosophical lectures can be of much service to those who are not familiarly acquainted with the technical language in which they are delivered."

It is presumed that an attentive perusal of these Dialogues, in which the principal and most common terms of science are carefully explained, and illustrated by a variety of familiar examples, will be the means of obviating this objection with respect to persons who may be desirous of attending those public philosophical lectures to which the inhabitants of the metropolis have almost constant access

CONTENTS.

MECHANICS.

ASTRONOMY.

MAGNETISM.

ELECTRICITY.

GALVANISM, OR VOLTAISM.

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MECHANICS.

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INTRODUCTION.

FATHER — CHARLES — EMMA.

Charles. My dear Papa, you told sister Emma and myself, the other day, that, after we had finished reading the "*Evenings at Home*," you would explain to us some of the principles of "NATURAL PHILOSOPHY:" will you be so kind as to begin this morning?

Father. Yes, my child; and I shall at all times take a delight in communicating to you the "ELEMENTS OF USEFUL KNOWLEDGE;" and the more so in proportion to the desire you exhibit of collecting such facts as may enable you to understand the operations of nature, as well as the works of ingenious artists, and lead you, insensibly, to admire the Wisdom and Goodness of the great Creator, by which the whole system of the universe is constructed and supported.

Emma. But can philosophy be comprehended by children so young as we are? I thought that it was the study and pursuit of men,—of old men too.

Fa. PHILOSOPHY is a word which, in its original sense, merely signifies *a love* or *desire of wisdom;* and you will not allow that you and your brother are so young as to have no desire for wisdom or knowledge.

Em. Far from it; I am convinced that the more knowledge I get, the better I like it; and the number of new ideas which, with a little of your assistance, I have gained from

the "*Evenings at Home*," and the great pleasure which I have received from the perusal of those volumes, will lead me to read them again and again.

Fa. If you have been so much delighted with the information you have acquired from "*The Evenings at Home*," how much more so must you be with that information, which explains the nature of every object around you, and accounts for the various changes to which they are perpetually subject by their actions on each other.

Em. I shall, indeed: and does *Natural Philosophy* give us this information?

Fa. It does; it explains the powers or principles of objects; their external appearances; and their elementary or component parts. It gives us the reason why a stone or other object thrown into the air returns again to the earth; how any object is put in motion, and why it subsequently stops: it accounts for the rising of smoke and vapour, and the descent of rain; the motions of the heavenly bodies and the changes of the seasons; and gives us also the causes of lightning and of thunder. It explains how we see ourselves in the looking-glass; and how objects are magnified, and brought nearer; and elucidates the force of fire and water, and the principles of animal and vegetable life. In fact, it is the *Science of Nature*, and is known under the name of *Physics* in its more comprehensive sense; and you will find very little, in the introductory parts of it, that will require more of your attention than many parts of that work with which you have been so lately delighted.

Ch. What a delightful! what an admirable study! How I long to be a philosopher.

Fa. But, my child, moderate your enthusiasm; the subject is so vast, that it will be a work of considerable time before you can be a proficient in it; and, above all things, remember throughout your whole application to it, that all the wonderful operations observable in nature are directed by the hand of an Almighty Providence, and are not the effect of chance. Nothing is done, nor can be done without the will of God, "in whom we live, and move, and have our being:" and let me add, if you pursue the study carefully and progressively, you will have but few difficulties to overcome.

Ch. But in some books of Natural Philosophy, which I

have occasionally looked into, a number of new and uncommon words have perplexed me. I have also seen references to figures, by means of large and small letters; the use of which I did not understand.

Fa. It is frequently a dangerous practice for young minds to dip into subjects before they are prepared, by some previous knowledge, to enter upon them; since it may create a distaste for the most interesting studies. Those books, for instance, which you now read with so much pleasure, would not have afforded you the least entertainment a few years ago, when you must have spelt out almost every word in each page. So likewise, the same sort of disgust would naturally be felt by those who should attempt to read works of science before the principles and leading terms of the introductory parts are well explained and understood. For this purpose it will be most important that you ascertain the derivation of every new and scientific word you meet with; and you will now discover that a knowledge of the Latin and Greek languages will be found indispensable for acquiring any science with facility and pleasure. We will begin with the word *Philosophy* itself. What did I tell you was its derivation?

Ch. I think you said it was from two Greek words, *phileo* (φιλέω) "I love," and *sophia* (σοφία) "wisdom;" and means "a lover of wisdom."

Fa. That is quite right. Now, remember, *Physics* comes from the Greek word *physis* (φύσις) "nature;" and means "the Science of Nature."

Em. Will you explain to me what is meant by *Experimental Philosophy?*

Fa. Natural Philosophy is a science of *observation* and *experiment*, for by these two modes we deduce the varied information we have acquired about material bodies: by the former we notice any changes that occur in the condition or relations of any body as they spontaneously arise without any interference on our part; whereas in the performance of an experiment, we purposely alter the natural arrangement of things to bring about some particular condition that we desire. To accomplish this we make use of various appliances, called *philosophical apparatus*, the proper use and application of which it is the office of *Experimental Philosophy* to teach.

And now we shall begin our lecture with the science of

Mechanics, which elucidates the causes that produce or prevent motion in bodies; the term is derived from the Greek word *mechane* (μηχανή) "a machine." The word *angle* is continually recurring in subjects of this sort. Do you know what an angle is?

Em. I think not. Will you explain what it means?

Fa. An *angle* is made by the opening of two straight* lines which intersect or meet one another. In this figure there are two straight lines, *ab* and *cb*, meeting at the point *b;* and the opening made by them is called an angle.

Fig. 1.

Ch. Whether that opening be small or great, is it still called an angle?

Fa. It is. Your drawing compasses will give you an excellent idea of an angle; the lines in the figure represent the legs of the compasses; and the point *b* the joint upon which they move or turn. Now you may open the legs to any distance you please, even so far that they shall form one straight line: in that position only they do *not* form an angle; but in every other situation, an angle is made by the opening of these legs; and the angle is said to be greater or less, as that opening is greater or less.

Em. Are not some angles called right angles?

Fa. Angles are either *right, acute,* or *obtuse.* When a line *ab* meets another line, *cd,* in such a manner as to make the angles *abd* and *abc* equal to one another, then those angles are called *right* angles; and the line *ab* is said to be perpendicular to the line *cd.* Hence, to be perpendicular to any thing, or to make *right* angles with, a line, or anything else, means one and the same thing. The corner of a room, or of a table, is generally a right angle.

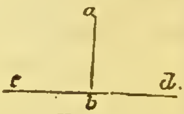


Fig. 2.

Ch. Does it signify how you repeat the letters of an angle?

Fa. An angle is usually expressed by three letters; and that at the angular point must always be the middle letter of the three: but it may often be expressed by a single letter: the angle *abc* in the figure 1, may be called simply the angle *b;* for there is no danger of a mistake, because there is but one angle at the point *b*.

Ch. I understand this: but if, in the second figure, I were

* *Straight* lines, in works of science, are usually denominated *right* lines.

to express the angle by the letter *b* only, you would not know whether I meant the angle *a b c* or *a b d*.

Fa. That is the precise reason why it is necessary, in various angles, to make use of three letters. An *acute* angle (fig. 1) *a b c*, is less than a right angle; and an *obtuse* angle (fig. 3) *a b c*, is greater than a right angle.

Fig. 3.

Em. You see now, Charles, the meaning of those letters placed against the figures, which so puzzled you before.

Ch. I do: they are intended to distinguish the separate parts of each, in order to render the description of them easier both to the author and the reader: but, Papa, if one side of an angle is made longer than the other, is not the angle larger?

Fa. No: an angle is not measured by the length of its sides, but, making the sides equal in length, by the width of the opening.

Em. How is that opening measured, Papa?

Fa. In this way; take your compasses, and with one leg on the angular point, describe a circle with the other that shall cut both sides of the angle; and you will thus see that an angle is a part of a circle: now, every circle is divided into 360 degrees, so that the wider the opening, the greater is the number of the degrees, and, therefore, the greater the angle. A *right* angle contains 90 degrees, and is, therefore, a quarter of a circle.

Em. Then, Papa, I suppose an *obtuse* angle contains more than 90 degrees, and an *acute* angle less?

Fa. Certainly; and now you will understand what I meant the other evening, when I told you that you should always snuff a candle at an angle of *forty-five* degrees, for, by so doing, a portion of the wick will be left high enough to retain the flame, and the danger of snuffing it out is avoided.

Em. I see this clearly, Papa. Now what is the difference between an angle and a triangle?

Fa. An angle, my dear, is made by the opening of two straight lines, and two straight lines cannot of themselves enclose a space; but a *triangle*, as *a b c*, does enclose a space, and is bounded by *three* straight lines. It takes its name from the property of containing *three angles;* and is derived from two Latin words,

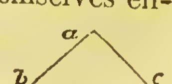


Fig. 4.

tres or *tria*, "three," and *angulus*, "a corner." There are various kinds of triangles, taking their names either from the extent of their sides, or from the nature of their angles; but as it is not worth while to burthen your memories with more terms than are absolutely necessary, I will omit the explanation of them till we have occasion to employ them. But I must not forget to explain to you the two important words, *Statics*, and *Dynamics*. Mechanics may be said to be divided into two great branches; that which relates to bodies in *a state of rest* is called *Statics*, from the Latin *stare*, "to stand:" and that which relates to bodies in a *state of motion* is called *Dynamics*, from the Greek word *dynamis* (*δύναμις*) "force or power." The former explains how a roof may be supported; the latter how it happens to fall, and why it fell in one direction rather than another, and likewise the time and the velocity of its falling.

Ch. Pray, Papa, what is the name of the science that teaches us a knowledge of angles?

Fa. Geometry; which, in the strict sense of the word, means simply the act of measuring the earth, as its derivation implies, being from the Greek *ge* (*γῆ*) "the earth," and *metron* (*μέτρον*) "a measure;" but it is applied now to that science which treats of magnitude and extension, and is, in that sense, the Handmaid of Mechanics, Astronomy, Hydrostatics, Pneumatics, the theory of Light, &c.

The study of Geometry has also another use, of much higher value to mankind; namely, that of teaching us to reason accurately on the most important subjects. It has a most powerful and salutary effect on the mind; it strengthens, corroborates, and directs the reasoning faculties; inuring the mind to patient labour, habituating it to strict method, and supplying it with ample means for contriving and adopting the most proper expedients for the prosecution of its inquiries, with a strict and perfect model of demonstration; Geometry, therefore, powerfully recommends itself to the diligent attention of every candid and impartial lover of truth; and it is on this account that it is so extensively pursued in the University of Cambridge.

But we may state that the study of Geometry presents, at its outset, many discouraging features; which, however, gradually disappear. A dense fog, to a person who had

never before seen one, would, at a distance, appear impenetrable; but, on advancing, it presents no obstacle, and, clearing away by degrees, is generally succeeded by a bright and glorious sunshine. Thus Geometry becomes easier as we proceed, and imparts such pleasure, from the certainty of its demonstrations, and the clearness of its conclusions, that the mind is insensibly led on from one truth to another, delighted with its own progress and discoveries.

Ch. What is meant by a *figure* in Geometry?

Fa. It is any part of space bounded by one or more lines, either straight or curved. When a figure has them both straight and curved, it is said to be a *mixed figure.*

Ch. A circle, I suppose, is a curved line, carried on till it meets at both ends, and is drawn from a point within, called the centre, and the curved line is termed the circumference. But what is meant by a geometrical or mathematical point?

Fa. A mathematical point has neither length, breadth, nor thickness. Hence it may be readily understood that a geometrical point cannot be seen, but is only imagined. Yet this idea has nothing to do with the reasoning part; all that becomes necessary is, that the point or dot should not occupy any sensible part of the line, in order that the diagram might be distinct. Points are only subservient to the convenience of construction.

Ch. When a straight line is drawn from one part of the circumference to another, through the centre, what is that line called?

Fa. It is termed the diameter of the circle. A line drawn from the centre to the circumference is called the *radius* of the circle. Hence the radius is the semi-diameter, or half-diameter of a circle. A straight line drawn from one point of a curve to another is a chord. When the parts of a circle are divided by a chord, they are called segments. When the chord is the diameter, the segments are equal, and are called semicircles.

Ch. How is a circle divided, Papa?

Fa. It is divided into 360 degrees, whatever be the size of the circle. That which the earth describes has no greater number of degrees than a small ring on the finger; the only difference being in their magnitude.

Ch. But are not circles otherwise divided?

Fa. They are also divided into great and smaller circles. The great circles go round the centre of the earth. The meridians are great circles, and the equator also. The admeasurement of a degree in a great circle is $69\frac{1}{10}$ English miles; but the smaller circles vary according to their distance from the equator. A circle divided by two diameters into four equal parts, will comprise four right angles; each one measuring 90 degrees.

QUESTIONS FOR EXAMINATION.

What is meant by the term philosophy? — What is an angle? — By what instrument can angles of different quantities be represented? — How many kinds of angles are there? — What is a *right* angle? — How do you define an angle? — What is an *acute* angle? — How do you define an *obtuse* angle? — For what purpose are letters used in the description of mathematical figures? — Can you tell me how to distinguish between an angle and a triangle? — What is geometry, and what its uses? — What is a figure in geometry? A circle? A radius? A semicircle? A chord? — What is the meaning of the word circumference? A mathematical point? Semidiameter?—How are circles divided? What is a great circle? A lesser circle? How measured? — What are meridians? The equator?—How many English miles are there in a degree upon the equator?

CONVERSATION II.

OF MATTER.

OF THE DIVISIBILITY OF MATTER.

Father. Do you understand, my dears, what philosophers mean when they make use of the word *Matter?*

Em. Are not all things which we see and feel composed of matter?

Fa. Everything which is the object of our senses is composed of matter, differently modified or arranged: but, in a philosophical sense, it is defined to be an *extended, impenetrable, inactive,* and *movable* substance.

Ch. If by *extension* is meant length, breadth, and thickness, matter, undoubtedly, is an extended substance. Its *impenetrability* also is manifest by the resistance it makes to the touch.

Em. And the other properties nobody will deny; for all material objects are, of themselves, without motion, which I suppose is what is meant by *inactive:* and yet, it may be readily conceived that, by the application of a proper force

there is no body which cannot be moved, whence it may be said to be *movable*. But I remember, Papa, that you told us something strange about the *divisibility* of Matter, which you said might be continued without end.

Fa. I did, some time ago, mention this as a curious and interesting subject; and this is a very fit time for me to explain it.

Ch. Can matter indeed be infinitely divided? For I suppose that this is what is meant by a division without end.

Fa. Difficult as this may at first appear, yet it seems very capable of proof. Can you imagine a particle of matter to be so small as not to have an upper and an under surface?

Ch. Certainly not; every portion of matter, however minute, must have two surfaces at least; and then I see that it follows of course that it is divisible; for the upper surface could be separated from the under one, and this again be repeated to infinity.

Fa. Your conclusion is just; matter is by some considered to be infinitely divisible, and many arguments besides yours have been advanced in support of that opinion; nevertheless it is impossible to imagine that the molecules of which you conceive matter to consist, can be composed of anything else than certain definite but excessively minute indivisible atoms, and this is the opinion now adopted by most philosophers, although it is perhaps a question which is incapable of satisfactory solution.

Em. But you were kind enough to say that you would mention to us some remarkable instances of the minute division of matter.

Fa. A few years ago a lady spun a single pound of wool into a thread 168,000 yards long: and Mr. Boyle mentions that two grains and a half of silk were spun into a thread of 300 yards in length. If a pound of silver, which contains 5760 grains, and a single grain of gold, be melted together, the gold will be equally diffused throughout the whole mass of silver; so that if one grain of the mass be dissolved in a liquid called *aqua fortis*, which is crude nitric acid, the gold will fall to the bottom. By this experiment it is evident that a grain may be divided in 5761 visible parts, for only the 5761st part of the gold is contained in a single grain of the mass.

Gold-beaters can spread a grain of gold into a leaf containing fifty square inches; and this leaf may be readily divided into 500,000 parts; each of which is visible to the naked eye. By the help of a microscope, which magnifies the area or surface of a body 100 times, the 100th part of each of these becomes visible; that is, the fifty millionth part of a grain of gold will be visible, or a single grain of that metal may be divided into fifty million visible parts. But the gold which covers the silver wire, used in making what is called gold lace, is spread over a much larger surface; yet it preserves, even if examined by a microscope, a uniform appearance. It has been calculated that one grain of gold, under these circumstances, would cover a surface of nearly thirty square yards.

In the gilding of buttons, five grains of gold which is applied as an amalgam with mercury, is allowed to each gross, so that the coating deposited must amount to the 110,000th part of an inch in thickness.

The *natural* divisions of matter are still more surprising. In odoriferous bodies, such as lavender-water, camphor, musk, asafœtida, and scents of various kinds, a wonderful subtlety of parts is perceived: for though they are perpetually filling a considerable space with odoriferous particles, yet these bodies lose but a very small part of their weight or quantity in a great length of time. One grain of musk has been known to perfume a room for the space of twenty years. In the perfume emanating from a flower, how diminutive must be the particles that reach the olfactory nerves of the nose when we smell them, and which are themselves invisible and cause no sensible diminution to the bulk of the plant.

The Lycoperdon, or puff-ball, is a fungus growing in the form of a tubercle, which, being pressed, bursts, emitting a dust so fine and so light, that it floats through the air with the appearance of smoke. Examined under the microscope, this dust, which is the seed of the plant, appears under the form of globules of an orange colour, perfectly rounded, and in diameter about the fiftieth part of a hair; so that if this calculation be correct, and a globule were taken having the diameter of a hair, it would be one hundred and twenty-five thousand times as great as the seed of the lycoperdon.

In Leslie's "Natural Philosophy" we read that millions of the

insect *Monas gelatinosa,* found among duck-weed, are sporting about in *one* drop of liquid: and that the *Vibrio undula,* found on the same plant, is computed to be ten thousand million times smaller than a hemp seed. Now, if it be admitted that these little animals are possessed of organized parts, such as a heart, stomach, muscles, veins, arteries, &c., and that they are possessed of a complete system of circulating fluids, similar to what is found in larger animals, we seem to approach to an idea of the infinite divisibility of matter. It has indeed been calculated that a particle of the blood of one of these animalcules is as much smaller than a globe one-tenth of an inch in diameter, as that globe is smaller than the whole earth. Nevertheless, if these particles be compared with the particles of light, it is probable that they would be found to exceed them in bulk as much as mountains exceed single grains of sand.

There is a very familiar example in the sweetening of tea, a small lump of sugar extending its influence throughout the entire cup-full ; and in one drop how diminutive must be the portion of sugar.

Again, a drop of port-wine put into a tumbler of water will tinge the whole mass, so that one drop of it can contain but a very minute portion of the wine.

A single grain of copper dissolved in nitric acid, will give a blue tint to three pints of water: by which the copper is attenuated at least one hundred million times.

I might enumerate many other instances of the same kind; but these, I doubt not, will be sufficient to convince you into what very minute parts matter is capable of being divided; and with these we will close our present conversation.

Fa. Now, my dear Charles, let me be the questioner, after our several conversations relating to the same subject, in order to find if you have entered into the spirit of the information you have received, and made such deductions as may be useful to you.

Ch. Most willingly, Papa.

Fa. You have learned, in this latter conversation, that matter is philosophically defined to be *an extended, impenetrable, inactive,* and *moveable* substance. How do you understand these terms?

Ch. Extension is that principle of matter by which it

occupies a part of space. *Impenetrability* implies a property by which two bodies cannot exist in the same place at the same time. *Inactive* and *moveable* apply to a body which resists, in any degree, a force impelling it to a change of state, with regard to motion and rest; but which *may* be moved, if sufficient force be applied to it.

Em. Of what shape are the ultimate particles of the generality of natural solids?

Fa. It is the opinion of most philosophers I have read, that they are, for the most part, *spherical;* but many different ideas have been formed as to the nature of matter. What is your opinion, now, after our conversation on the subject?

Ch. Matter is said to be infinitely divisible; and many are the arguments advanced in support of that hypothesis; yet, it can only be divisible as being composed of atoms; but an atom cannot be divided by any natural means.

Em. Is there, then, any difference between matter and body?

Fa. Yes: for although bodies are composed of matter, those terms are not strictly synonymous. Bodies are capable of being divided; because the atoms of which they are composed may, by various means, be separated. The attenuation of gold on wire, of which mention has been made, is not perhaps, strictly speaking, a division of matter, but of body.

Ch. Are bodies of themselves *inactive,* or *inert?*

Fa. They must be so until they are forced into action. It has been well observed, in elucidation of this fact, that a tranquil pool of water is inert; but when made to fall on a mill-wheel, it becomes an *immensely active power.*

You are becoming quite a philosopher, Charles; we will next explain the *Attraction of Cohesion.*

QUESTIONS FOR EXAMINATION.

Of what is everything which we see and feel composed? — How is *matter* defined? — How do you know it is extended and impenetrable? — Do you recollect any remarkable instances of the minute division of matter? — What instances can you give of the minute divisions of matter in nature? — How do you compare the size of a particle of blood? — Are not the particles of light very small?

CONVERSATION III.

OF THE ATTRACTION OF COHESION.

Father. Well, my dear children, have you reflected upon our last conversation? Do you comprehend the several instances which I enumerated as examples of the minute division of matter?

Em. Indeed, Papa, the examples which you gave us very much excited my wonder and admiration; and, from the thinness of some leaf gold which I once had, I can readily credit all you have said on that part of the subject. But I cannot imagine such small animals as Mr. Leslie describes in his natural history: and I am still more at a loss to comprehend that animals so minute should possess all the properties of the larger one; such as a heart, veins, blood, &c.

Fa. By the help of my solar microscope, I can show you, the next bright morning, very distinctly, the circulation of the blood in a flea: and, with better glasses than those which my microscope possesses, the same appearance might be seen in creatures still smaller than the flea; even in those which are themselves invisible to the naked eye. But we shall converse more at large on this subject when we come to consider Optics, and the construction and use of the Solar Microscope. At present we will turn our thoughts to that principle in nature which philosophers have agreed to call *Gravity*, or *Attraction;* and without which properties solid bodies would all crumble to atoms.

Ch. If there be no more difficulties in philosophy than we met with in our last Lecture, I do not fear but that we shall, in general, be able to understand it. Are there not, Papa, several kinds of attraction?

Fa. Yes, there are: two of which it will be sufficient for our present purpose to describe. One is the *attraction of cohesion:* the other, that of *gravitation.* The *attraction of cohesion* is that power which keeps the parts of bodies together when they touch, and prevents them from separating, or which inclines the parts of bodies to unite, when they are placed sufficiently near to each other. *Attraction* is derived from two

Latin words, *ad*, "to," and *traho*, "I draw:" and *cohesion* from the Latin word, *cohæreo*, "I hold together."

Ch. Is it, then, by the *attraction of cohesion* that the parts of this table, or of this marble-slab, are kept together?

Fa. The instances which you have selected are accurate; but you might have said the same of every other solid substance in the room; and it is in proportion to the different degrees of attraction with which different substances are affected, that some bodies are hard, others soft, others tough, thick, thin, &c. The three different forms which matter assumes—solid, liquid, and gaseous—are determined by the degree of cohesive force existing among the elementary particles. In solids it is the great quantity of this force which causes *solidity;* in *liquids* it is less powerful, and in *gases* or aeriform fluids, its force is so imperceptible as to assume rather a *repulsive* than an *attractive* tendency. The cohesive power of bodies cannot be accurately ascertained; but various experiments have been made to ascertain the different degrees of cohesion, belonging to the various kinds of wood, metals, and other substances. You will find much information on this subject in Leslie's Natural Philosophy; and in the experiments of Professor Barlow in his work on "The strength of materials," and in the experiments of Mr. George Rennie, and likewise in Young's Lectures on Natural Philosophy.

Ch. You once showed me that two leaden bullets having a little scraped from their surfaces, would in some way stick together with great force. You called that, I think, the *attraction of cohesion?*

Fa. No, my dear; this is not exactly *cohesion*, but *adhesion;* there is this difference, *cohesion* is that force of attraction by which the particles of a body are kept attached to each other, and also by which they resist separation; while *adhesion* is that attractive force existing between two *different* bodies brought into contact, as a drop of water on a piece of glass, or the two leaden bullets you are alluding to: those who have made this experiment with great attention and accuracy, do assert, that if the flat surfaces which are presented to one another be but a quarter of an inch in diameter, scraped very smooth, and forcibly pressed together with a twist, a weight of a hundred pounds is frequently required to separate them.

As it is by the attraction of cohesion that the parts of

solid bodies are kept together, so when any substance is separated or broken, it is only the attraction of cohesion that is overcome in that particular part.

Em. Then, Papa, when I had the misfortune, this morning at breakfast, to let my saucer fall from my hands to the ground, by which it was broken into several pieces, was it only the *attraction of cohesion* that was overcome by the parts of the saucer being separated by its fall?

Fa. Certainly: for, whether you unluckily break the china, or cut a stick with your knife, or melt lead over the fire, as your brother sometimes does, in order to make plummets, these and a thousand other instances which are continually occurring, are but examples in which the cohesion is overcome by the fall, the knife, or the fire.

Em. The broken saucer being highly valued by Mamma, she has taken the pains to join it again with white lead. Was this performed by means of the *attraction of cohesion?*

Fa. It was, my dear: and hence you will easily learn that many operations in the arts and in cookery are, in fact, nothing more than different methods of effecting this attraction. Thus flour, by itself, has little or nothing of this principle; but when mixed with milk, or other liquids, to a proper consistency, the parts cohere strongly; and this cohesion, in many instances, becomes still stronger by means of the heat applied to it in boiling or baking.

Ch. You put me in mind, Papa, of the fable of the man blowing hot and cold: for, in the instance of the *lead,* fire overcomes the attraction of cohesion; and the same power, heat, when applied to puddings, bread, &c., causes their parts to cohere more powerfully. How are we to understand this?

Fa. I will endeavour to remove your difficulty. Heat expands all bodies without exception, as you shall see before we have finished our lectures. Now, fire applied to metals, in order to melt them, causes such an expansion of their particles, that they are thrown out of each other's attraction; whereas the heat communicated in the operations of cookery is sufficient to expand the particles of flour, but is not enough to overcome the attraction of cohesion. Besides, your Mamma will tell you that the heat of boiling would frequently disunite the parts of which her puddings are composed if she did not take the precaution of enclosing them in a cloth, leaving them just room

enough to expand without the liberty of breaking to pieces; and the moment they are taken from the water they lose their superabundant heat and become solid.

Em. When the cook makes broth, it is the heat, therefore, that overcomes the attraction which the particles of meat have for each other; for I have seen her pour off the broth, and the meat is all in rags. But will not the heat overcome the attraction which the parts of the bones have for each other?

Fa. The heat of boiling water will never effect this; but a machine was invented several years ago, by a Mr. Papin, for that purpose. It is called Papin's Digester, and has been employed in taverns, and in many large families, for the purpose of dissolving bones; and it effects it as completely as a less degree of heat will liquefy jelly. On some future day I will show you an engraving of this machine, and explain its different parts, which are extremely simple.*

QUESTIONS FOR EXAMINATION.

What instrument is used to discern very small objects? — What are the kinds of gravity which are applicable to the science of MECHANICS? — How do you define the *attraction of cohesion?* —What is the cause that some bodies are soft, others hard, &c.?—How is the power of cohesion exhibited in the case of leaden bullets? — What is the cause of things being broken? — Give me some instances in which the attraction of cohesion is overcome? — Is the principle of cohesion applicable to the operations of cookery? — Does heat in some instances weaken the power of the attraction, and in others make it act more powerfully?—Can you explain the reason of this? — Upon what principle is broth made? — How are bones dissolved?

CONVERSATION IV.

OF THE ATTRACTION OF COHESION—*continued.*

Father. I will now mention some other instances of this great law of nature. But, observe first, that no sensible attraction takes place in those bodies whose surfaces are rough and uneven, for though in actual contact, yet they touch each other only by a few points: if I lay a book on the table it will not adhere because of the roughness of the

* See Conversation XIX.

binding, and therefore so few of the particles of its surface come in contact with the table; but surfaces perfectly flat and well polished, placed in contact, have their particles approach in sufficient number, and closely enough to produce a sensible degree of cohesive attraction. If two polished plates of marble, or brass, or two pieces of glass, be put together, they will adhere so powerfully as to require a very considerable force to separate them. Two globules of quicksilver placed very near to each other will run together and form one large drop. Drops of water will do the same. Two circular pieces of cork placed upon water, about an inch apart, will run together. Balance a piece of smooth board on the end of a scalebeam ; then let it lie flat on water; and five or six times its own weight will be required to separate it from the water. Dr. Brook Taylor adopted this method to estimate the force of *adhesion.* If a small globule of quicksilver be laid on clean paper, and a piece of glass be brought into contact with it, the quicksilver will adhere to it, and be drawn away from the paper; but bring a larger globule into contact with the smaller one, it will forsake the glass and unite with the other quicksilver.

Ch. Did not you tell me, Papa, that it was by means of the *attraction of adhesion* that a little tea left at the bottom of the cup instantly ascends a lump of sugar when thrown into it?

Fa. The ascent of water or other liquids in sugar, sponge, and all porous bodies, is a species of this attraction: but it is called *capillary attraction.* It is thus denominated from the property which tubes of a very small bore, scarcely larger than to admit a *hair,* possess of causing water to stand above its level. The word *capillary* is from *capillus,* the Latin word for *hair.*

Ch. Is this property visible in no other tubes than those whose bores are so exceedingly fine ?

Fa. Yes; it is very apparent in tubes whose diameters are one-tenth of an inch, or more; but the smaller the bore, the higher the fluid rises; for it ascends, in all instances, till the weight of the column of water in the tube balances, or is equal to the attraction, of the tube. By immersing glass tubes of different bores in a vessel of coloured water, you will see that the water rises as much higher in the smaller tube,

than in the larger, as its bore is less than that of the larger. The water will rise a quarter of an inch in a tube whose bore is about one-eighth of an inch in diameter, and there remain suspended.

This kind of attraction is well illustrated by taking two pieces of glass joined together at the side *bc*, and kept a little open at the opposite side *ad*, by a small piece of cork, *e*. In this position immerse them in a dish of coloured water, *fg*, and you will observe that the attraction of the glass at, and near *bc*, will cause the fluid to ascend to *b*: whereas, about the parts *d*, it scarcely rises above the level of the water in the vessel.

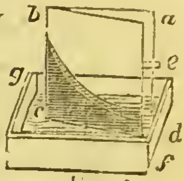


Fig. 5.

Ch. I see that a curve is formed by the water.

Fa. Even so; and to this curve there are many curious properties belonging, as you will hereafter be able to investigate for yourself. A lump of sugar, sponge, bread, linen, blotting-paper, and all porous substances, may be considered as collections of *capillary* tubes; for if one extremity be brought in contact with water, the fluid will pass completely through it and wet the whole substance. A mass of wetted thread, or a towel hanging over the edge of a basin from the water within it, will, by *capillary* action, completely empty it. The rise of the oil or spirit in the wick of a lamp, of the sap in trees, and the functions of the excretory vascular system in plants and animals, depends on *capillary* attraction.

Em. Is it not upon the principle of the *attraction of cohesion* that carpenters glue their work together?

Fa. It is; and upon the same principle braziers, tinmen, plumbers, &c., solder their metals; smiths also unite different bars of iron, by means of heat, and bricklayers and masons unite their materials by means of mortar and cement. These and a thousand other operations, which we continually witness, depend on the same principle as that which induced your Mamma to use the white lead in mending her saucer. But you must bear in mind that although white lead is frequently used as a cement for broken china, glass, and earthenware, yet, if the vessels are to be brought again into use it, is not a safe cement, because it is an active poison; besides, one much stronger has been discovered, I believe, by a very

able and ingenious philosopher, the late Dr. Ingenhouz; at least I had it from him several years ago: it consists simply of a mixture of quick-lime and white of egg, or newly-made cheese, rendered soft by warm water, and worked up to a proper consistency.

Em. Is it possible, dear Papa, that such a great philosopher as I have heard you say Dr. Ingenhouz was, could attend to things so trifling?

Fa. He was a man deeply skilled in many branches of science; and I hope that you and your brother will one day make yourselves acquainted with many of his important discoveries. No real philosopher will consider it beneath his attention to add to the conveniencies of life.

Ch. This attraction of cohesion seems to pervade the whole of nature.

Fa. It does: but you will not forget that it acts only at very small distances. Some bodies, indeed, appear to possess a power the reverse of the attraction of cohesion.

Em. What is that, Papa?

Fa. It is called *repulsion*. Thus, water repels most bodies till they are wet. A small needle, rubbed with oil, and carefully placed on water, will swim: and flies may walk on water without wetting their feet,

> Or bathe unwet their oily forms, and dwell
> With feet repulsive on the dimpling well."

The vapour we call dew, and rain also, in descending assume by *attraction* the form of drops: now the drops of dew, which early in the morning appear on plants, particularly on blades of grass and cabbage plants, where they assume a globular form from the mutual attraction existing in the particles of water, will be found, on examination, not to adhere to the leaves; for they will roll off in compact bodies; which could not be the case if there subsisted any degree of attraction between the water and the leaf.

If a small thin piece of iron be laid upon quicksilver, the *repulsion* between the different metals will cause the surface of the quicksilver near the iron to be depressed.

The repelling force of the particles of a fluid is but small: therefore, if a fluid be divided, it easily unites again; but if

glass or any hard substance be broken, the parts cannot be made to adhere without being first moistened; because the repulsion is too great to admit of a re-union.

The repelling force between water and oil is likewise so great, that it is impossible to mix them in such a manner as to prevent their separation.

If a ball of light wood be dipped in oil, and then put into water, the water will recede so as to form a small channel round the ball.

I may add here, that there is no attraction of cohesion between the separate parts of pulverized bodies; grains of powder, sand, &c., have no sensible attraction, because they are not in sufficiently close contact.

Ch. How is it, Papa, that cane, steel, and many other things, can be bent without breaking, and, when set at liberty again, recover their original form?

Fa. The circumstance of a piece of steel, or cane, recovering its usual form after being bent, is owing to a certain power, called *elasticity;* which may, perhaps, arise from the particles of those bodies, though disturbed, not being drawn out of each other's attraction: therefore, as soon as the force upon them ceases to act, they restore themselves to their former position. The term *elastic* is derived from the Greek *elaste* (ἐλαστη) "a spring," from *elauno* (ἐλαυνω) "I draw."

What have you now learned from the two latter conversations?

Ch. I find, first, that particles, possessed of large surfaces of contact, adhere most strongly together; and secondly, that those particles which touch each other in a few points, compose soft and fluid bodies, on account of the small force with which their parts adhere together. This is probably the cause of elasticity in some bodies; as it seems to depend on the cohesive force which restores the particles to their first relative situation, when, by any external impulse, they have been removed to a very small distance from each other.

Fa. What further observations have you to make?

Ch. I think I understand that the particles of matter whose attraction is but very little more than their weight, constitute a fluid; that those particles whose weight is greater than their attraction can produce only an incoherent mass, like a heap of sand; that those particles whose attraction is very much

greater than their weight form a compact and solid body; and that, if the attraction exceed the weight of the particles in only a moderate degree, they will compose a soft body.

QUESTIONS FOR EXAMINATION.

Mention some instances in which the attraction of cohesion acts. — Upon what principle does water or other liquids ascend in sugar, sponge, &c.?—From whence does the term capillary attraction arise? — Does capillary attraction act in any tubes except those of exceedingly fine bores?— What experiments will show capillary attraction? — Upon what principle do carpenters and others glue the several parts of their work together? — Do you recollect any other instances of the action of the principle of cohesion? — How does the principle of cohesion act? What do you mean by *repulsion?*— Mention some instances in which the power of repulsion appears to act? — Why do cane, steel, and many other things, after being bent, recover their original form again?—How is elasticity accounted for?

CONVERSATION V.

OF THE ATTRACTION OF GRAVITATION.

Father. We will now proceed to discuss another very important and general principle in nature; namely, the *attraction of gravitation*, or, as it is frequently termed, *gravity;* which is the power inclining *distant* bodies towards each other. Of this we have perpetual instances in the falling of bodies to the earth; and we may at the same time observe, that the same cause which occasions the fall of bodies produces also their weight; in other words, it is the *attraction of gravitation* which makes bodies heavy; the power which brings bodies that are unsupported to the ground, causes those which are supported to press upon the objects which prevent their fall with a weight equal to the force with which they gravitate towards the earth. This power, which is inherent in the earth, is called the *force of gravity;* the act of a body pressing downwards towards the earth, is called the *gravitation* of that body; and the exact amount of gravitation residing in any body is termed *the weight* of that body.

Ch. Am I, then, to understand that, whether this marble fall from my hand, or a loose brick from the top of the house,

or an apple from a tree, all these fall by the *attraction of gravity?*

Fa. It is by the power commonly expressed under the term *gravity* that all bodies whatever have a tendency to the earth; and, unless supported, they will fall to the earth in lines nearly perpendicular to its surface: the term *gravity* is from the Latin word *gravis*, " heavy."

Em. But are not smoke, steam, and other light bodies, which we see ascend, exceptions to the general rule?

Fa. It appears so, at first sight; and it was formerly received as a general opinion that smoke, steam, &c. possessed no weight. The discovery of the air-pump has, however, shown the fallacy of this notion; for in an exhausted receiver (that is, in a glass jar, from which the air has been withdrawn by means of the air-pump) smoke and steam descend by their own weight as completely as a piece of lead. When we come to converse on the subjects of Pneumatics and Hydrostatics, you will understand that the reason why smoke and other bodies ascend is simply because they are lighter than the atmosphere which surrounds them; and the moment they reach that part of it which has the same gravity as themselves, they cease to rise. Upon the same principle a cork, or a drop of oil, if forced to the bottom of a vessel of water, rises to the top as soon as it is set at liberty.

Ch. Is it, then, by this power of *gravity* that all terrestrial bodies remain firm on the earth?

Fa. By *gravity*, bodies on all parts of the earth (which you know is nearly of a globular form) are kept on its surface; because they all, wherever situated, tend to the centre; wherefore, the inhabitants of New Zealand, although nearly opposite to our feet, stand as firmly on the earth as we do in Great Britain.

Ch. This is difficult to comprehend: nevertheless, if bodies on all parts of the surface of the earth have a tendency to the centre, there seems no reason why bodies should not stand as firmly on one part as on another. Does this power of *gravity* act alike on all bodies?

Fa. It does, without any regard to their figure, or size; for *attraction*, or *gravity*, acts upon bodies in proportion to the quantity of matter which they contain; that is, four times a greater force of gravity is exerted upon a weight of four pounds, than upon one of a single pound. So, also, a body

consisting of 1000 particles of matter, requires ten times the force of attraction to bring it to the ground in the same space of time, that a body consisting of only 100 particles does. If you draw towards you two bodies, the one of 100, the other of 1000lbs. weight, will you not be obliged to exert ten times as much strength to draw the heavier one to you in the same time that would be required for the lighter one? The consequence of this principle is, that all bodies, at equal distances from the earth, fall with equal velocity.

Em. What do you mean, Papa, by *velocity?*

Fa. I will explain it by an example or two. If you and Charles set out together, and *you* walk a mile in half an hour, but *he*, by walking and running, gets over two miles in the same time, how much swifter will he go than you?

Em. Twice as swift.

Fa. He does; because, *in the same time*, he passes over twice as much space; therefore we say his velocity is twice as great as yours. Suppose a ball, fired from a cannon, to pass through 800 feet in a second of time, and in the same time your brother's arrow passes through 100 feet only, how much swifter does the cannon ball fly than the arrow?

Em. Eight times swifter.

Fa. Then it has eight times the *velocity* of the arrow: and hence you understand that swiftness and velocity are synonymous terms, and that the velocity of a body is measured by the space it passes over in a given time, as a second, a minute, an hour, &c.

Em. If I let a piece of metal, as a penny-piece, and a feather fall from my hand at the same time, the penny would reach the ground much sooner than the feather. How do you account, Papa, for this, if all bodies are equally affected by gravitation, and descend with equal velocity, when at the same distance from the earth?

Fa. Though the penny-piece and feather will not, in the open air, fall with equal velocity, yet, if the air be taken away, which is easily done by a little apparatus connected with the air-pump, they will descend in the same time: therefore, the true reason why light and heavy bodies do not fall with equal velocity is, that the *former*, in proportion to its weight, meets with a much greater resistance from the air than the *latter*.

Ch. It is then from the same cause, I imagine, that, if I drop a penny and a piece of wood into a vessel of water, the penny will reach the bottom, but the wood, after descending a little, rises to the surface.

Fa. In this case, the resisting medium is water instead of air; and the copper penny, being about nine times heavier than its bulk of water, falls to the bottom without any apparent resistance; while the wood, from being much lighter than water, swims on its surface; by its *momentum*, however, it sinks a little, yet, as soon as that is overcome by the resisting medium, it rises as before observed. The term *momentum* I will explain in our next conversation.

QUESTIONS FOR EXAMINATION

How is the attraction of gravitation defined?—Give some familiar instances in which the law of gravity or gravitation acts.—In what direction do bodies fall towards the earth?—Is this a general law without any exceptions?—By what power, and why do bodies remain firm on the earth?—How is it that gravity acts alike on all bodies?—Do bodies at equal distances from the earth fall towards it with equal velocity?—Explain to me what is meant by velocity.—Are velocity and swiftness synonymous terms?—How is the velocity of a body measured?—If a penny-piece and a feather be let fall together, how is it that the penny reaches the ground first?—Suppose the penny and a piece of wood be let fall in a vessel of water, why does the copper go to the bottom, and the wood, after a short descent, rise again to the surface?

CONVERSATION VI.

OF THE ATTRACTION OF GRAVITATION.

Emma. The term *momentum*, which you made use of yesterday, you promised to explain to us, to-day: what is it, Papa?

Fa. If you have understood what I have said respecting the velocity of moving bodies, you will easily comprehend what is meant by the word momentum.

The *momentum*, or moving force of a body, is the *quantity of matter* multiplied by its *quantity of motion;* that is, its weight multiplied into its velocity. The quicker a body moves, the greater will be the force with which it will strike against another body. For instance, you may place very gently a pound-weight upon a china plate without any danger

of breaking it; but if you let it fall from the height of only a few inches, it will dash the china to pieces. In the first case, the plate has only the pound weight to sustain; in the other, it has to sustain the weight multiplied into the velocity, or, to speak in a more simple manner, the weight is to be multiplied into the distance from which it fell.

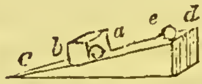


Fig. 6.

If a ball *a* merely lean against an obstacle *b*, it will not be able to overturn it; but if it be taken up to *e*, and suffered to roll down the inclined plane *cd* against the obstacle *b*, it will certainly overthrow it. In the former case, *b* would only have to resist the weight of the ball *a;* in the latter, it has to resist the weight multiplied into its motion, or velocity.

Ch. The momentum, therefore, of a small body, whose velocity is very great, may be equal to that of a very large body with a slow motion, that is, whose velocity is small.

Fa. It may: and hence you see the reason why the immense battering rams, used by the ancients in the art of war, have given place to cannon balls of but a few pounds weight.

Ch. I do: for what is wanting in weight is made up by velocity.

Fa. Can you tell me what velocity a cannon ball of 28 pounds must have to effect the same purpose as would be produced by a battering ram of 15,000 pounds weight, and which by manual strength could be moved at the rate of only two feet in a second of time?

Ch. I think I can. The *momentum* of the battering ram must be estimated by its weight, multiplied into the space passed over in a second, that is, the 15,000 must be multiplied by the two feet, which equals 30,000, which is the *momentum:* now, this must also be the momentum of the cannon ball, and if it be divided by the weight of the ball, it will give the velocity required; thus 30,000 divided by 28, will give a quotient of 1072 nearly, which is the velocity, or number of feet which the cannon ball must pass over in a second of time, in order that the momentum of the battering ram and the ball may be equal; or, in other words, that they may have the same effect in beating down an enemy's wall.

Em. I now fully comprehend what the *momentum* of a body is: for if I let a stone or ball accidentally fall upon my

foot, it gives me more pain than the pressure only of a weight several times heavier.

Ch. If the attraction of gravitation be a power by which bodies in general tend towards each other, why do all bodies tend to the earth as a centre?

Fa. I have already told you that by the great law of gravitation, the attraction of all bodies is in proportion to the quantity of matter which they contain. The earth, therefore, being so immensely large, in comparison with all other substances in its vicinity, destroys the effect of this attraction between smaller bodies by bringing them all to itself. If we let fall two balls, at a small distance apart, from a high tower, although they have an attraction for each other, yet we shall find that it will be as nothing when compared with the attraction by which they are both impelled to the earth: consequently, the tendency which they mutually have of approaching one another will not be perceived in the fall. If, however, any two bodies were placed in free space, and out of the sphere of the earth's attraction, they would, in that case, assuredly fall towards each other, with a velocity proportioned to their nearness. If the bodies were equal, they would meet in the middle point between the two; but if they were unequal, they would then meet nearer the larger one, in proportion to the quantity of matter which that contained.

Ch. According to this law, then, the earth ought to move towards falling bodies as well as those bodies move towards the earth.

Fa. Certainly it ought; and, in theory, it does so; but when you calculate how many million of times larger the earth is than anything belonging to it; and observe the comparatively small distances from which bodies can possibly fall, you will then know that the point where the falling bodies and earth will meet is at a distance from its surface far too small to be conceived by the human imagination. You may possibly imagine, too, that, according to this theory, the hills would attract the houses and churches towards them. The hills no doubt exert this influence, but they cannot move the buildings, because they can neither overcome the attraction of cohesion between the bricks and mortar, nor that of gravity, which fixes the wall to the ground. There are, however, some instances in which the attraction of a large body has

sensibly counteracted that of the earth. If a man, standing on the declivity of an abrupt mountain, hold a plum-line in his hand, the weight will not fall perpendicularly to the earth, but incline a little towards the mountain; and this is owing to the lateral or side attraction of the mountain interfering with the perpendicular attraction of the earth.

We will resume the subject of *Gravity* to-morrow.

QUESTIONS FOR EXAMINATION.

What is the meaning of the term *momentum?* — Can you show by any familiar instance that it does not mean weight? — Turn to figure 6, and explain the difference between momentum and weight. — Which of two equal balls will have the greater momentum, the one that falls down an inclined plane, or the other that falls perpendicularly? — How can the momentum of a small body be made equal to that of a large one which has only a given velocity? — Why have cannon-balls superseded the use of battering-rams in the art of war?* — Why does a ball or other body falling upon the foot occasion more pain, than the mere pressure of a much heavier body? — From how high in the air must I let fall a body in order that it may come to the ground with eight times the force which it would have had, if laid gently down? — What is the rule by which this is estimated? — If two equal balls descend, one from the height of twelve inches, and the other from that of twenty-four inches, will the momentum of the one be double of that of the other? — Why do all bodies tend to the centre of the earth? — Why do not falling bodies which happen to be near each other approach still nearer by means of the attraction of gravitation? — If two bodies, very remote from each other, fall towards the earth, will they descend in parallel lines? — What would be the consequence if two bodies were placed in free space, and out of the sphere of the earth's attraction? — Where would they meet if the bodies were equal? — Does the earth move towards falling bodies? — If two bodies of unequal weights were falling towards each other, which of them would have the greater velocity?

CONVERSATION VII.

THE ATTRACTION OF GRAVITATION—*continued.*

Emma. Has the Attraction of Gravitation, Papa, the same effect on all bodies, whatever be their distance from the earth?

Fa. No: this, like every power which proceeds from a centre, decreases as the squares of the distances from that centre increase.

* Here the pupil may be referred to the examples in p. 25

Em. I fear that I shall not understand this, Papa, unless you illustrate it by examples.

Fa. Well, then: suppose of an evening you are reading at the distance of one foot from a candle, and that you receive a certain quantity of light on your book; now, if you remove to the distance of two feet from the candle, you will, by this law, receive four times less light than you had before. Here then, although you have increased your distance but two-fold, yet the light is diminished four-fold, because four is the square of two, or two multiplied by itself. If, instead of removing two feet from the candle, you take your station at the distance of 3, 4, 5, or 6 feet, you will then receive at the different distances, 9, 16, 25, or 36 times less light than when you were within one foot from the candle; for these, as you know, are the squares of the numbers 3, 4, 5, and 6. The same is applicable to the *heat* imparted by a fire; at the distance of one yard from which, a person will enjoy four times as much heat as he who is situated two yards from it; and nine times as much as one removed to the distance of three yards.

Ch. Is, then, the attraction of gravity four times less at a yard distance from the earth than it is at the surface?

Fa. No: whatever be the cause of attraction, which to this day remains undiscovered, it acts from the *centre* of the earth, and not from its surface; and hence the difference of the power of gravity cannot be discerned at the small distances to which we can have access; for a mile, or two, which is much higher than, in general, we have opportunities of making experiments, is nothing in comparison of 4000 miles, the distance of the centre from the surface of the earth. But could we ascend 4000 miles above the earth, and, of course, be double the distance that we are now from the centre, we should there find that the attractive force would be but one-fourth of what it is here; or, in other words, that a body which, at the surface of the earth, weighs one pound, and, by the force of gravity, falls through sixteen feet in a second of time, would, at 4000 miles above the earth's surface, weigh but a quarter of a pound, and fall only four feet in a second.

Suppose it were required to find the weight of a leaden ball, at the top of a mountain three miles high, which on the surface of the earth weighs 20lbs.

If the semi-diameter of the earth be taken at 4000, then

add to this the height of the mountain, and say, as the square of 4003 is to the square of 4000, so is 20 lb. to a fourth proportional; or as 16024009 : 16000000 : : 20 : 19·97 or something more than 19 lb. $15\frac{1}{2}$oz. which is the weight of the leaden ball at the top of the mountain.

Em. How is that known, Papa? No person was ever so far from the earth's surface.

Fa. True, my dear; for the most enterprising of our aëronauts, or balloon adventurers, have ascended but a little way in comparison of the distance that we are speaking of. However, I will try to explain the method by which philosophers have come at their knowledge on this subject.

The moon is a heavy body connected with the earth by this law of attraction; and, by the most accurate observations, it is known to be obedient to the same laws as other heavy bodies are: its distance is also clearly ascertained to be about 240,000 miles, which is sixty semi-diameters of the earth; and of course the earth's attraction upon the moon ought to diminish in the proportion of the square of this distance; that is, it ought to be 60 times 60, or 3600 times less at the moon than it is at the surface of the earth. This is found to be the case.

Again, the earth is not a perfect sphere, but a spheroid; that is, of the shape of an orange, rather flat at the two ends called the poles; and the distance from the centre to the poles is about eighteen or nineteen miles less than the distance from the centre to the equator: consequently, bodies ought to be somewhat heavier at and near the poles than they are at the equator; which is also found to be the case. Hence it is inferred that the Attraction of Gravitation varies at all distances from the centre of the earth in proportion as the squares of those distances increase.

Ch. It seems very surprising that philosophers, who have discovered so many things, have not been able to find out the cause of gravity. Could not Sir Isaac Newton, had he been asked why a marble, dropped from the hand, falls to the ground, have assigned the reason for it?

Fa. That great man, probably the greatest man that ever adorned this world, was as modest as he was great; and he would have told you he knew not the cause.

The late excellent and learned Dr. Price, in a work which

he published many years ago, asks, "Who does not remember a time when he would have wondered at the question *Why does water run down hill?* What *ignorant* man is there who is not persuaded that he really understands this perfectly? But every *improved* man knows it to be a question he cannot answer." The descent of water, my dear children, like that of other heavy bodies, depends upon the *attraction of gravitation;* the cause of which is still involved in darkness.

Em. You just now said that heavy bodies, by the force of gravity, fall sixteen feet in a second of time. Is that always the case?

Fa. Yes: all bodies near the surface of the earth fall at that rate in the first second of time; but, as the attraction of gravitation is continually acting, so the velocity of falling bodies is an increasing, or, as it is usually called, an *accelerating* velocity. It is found, by very accurate experiments, that a body descending from a considerable height by the force of gravity falls 16 feet in the first second of time; 3 times 16 feet in the next; 5 times 16 feet in the third; 7 times 16 feet in the fourth; and so on, continually increasing according to the odd numbers, 1, 3, 5, 7, 9, 11, &c. Though, perhaps, I ought to be more particular in stating that in our latitude the exact distance an object passes in the first second is $16\frac{1}{12}$ feet.

QUESTIONS FOR EXAMINATION.

By what law does the attraction of gravitation act? — Can you illustrate it by examples? — How much less light shall I receive from a candle at the distance of *six* feet, than I should if I were only *two* feet from it? — How much more warmth shall I feel at the distance of *three* feet from a fire, than you will being placed at *eight* feet from it? — Does the force of gravity act from the surface or the centre of the earth? — Can the *difference* of the power of gravity be discerned at the small distances to which we can have access? — What would a piece of lead weigh at 4000 miles above the surface of the earth that weighs a hundred weight on the surface? — Through what space does a heavy body fall on the surface of the earth in a second of time; and how far would it fall, in the same time, at the distance of 4000 miles above the surface of the earth? — At what distance is the moon from us, in miles and in semi-diameters of the earth? — How much less does the attraction of the earth act at the distance of the moon, than it would at 4000 miles from the surface of the earth? — What is the shape of the earth? — Would any body (as a block of stone, or a lump of lead) weigh heavier at the poles or the equator of the earth? — Upon what does the descent of water down a hill depend? — Is the velocity of falling bodies continually the same: if not, by what proportion does it increase?

CONVERSATION VIII.

THE ATTRACTION OF GRAVITATION—*continued.*

Emma. Resuming our conversation on *gravity*, would a ball of twenty pounds weight, Papa, at this place, weigh half an ounce less at the top of a mountain?

Fa. Certainly: but you would not be able to ascertain it by means of scales and weights, because both the weight and the thing to be weighed being in similar situations would lose equal portions of their gravity.

Em. How, then, would you make the experiment?

Fa. By means of one of those steel spiral-spring instruments which you have seen occasionally used, the fact might be ascertained.

Ch. I think, from what you told us yesterday, that with the assistance of your stop-watch I could tell the height of any place by observing the number of seconds that a marble or any other heavy body would take in falling from that height.

Fa. How would you perform the calculation?

Ch. I should go through the multiplications you gave us at the close of our last conversation, according to the number of seconds, and then add them together.

Fa. Explain yourself more particularly by answering me this problem. Suppose you were to let a marble or a penny-piece fall down a deep dry well, and that it was exactly five seconds in effecting the descent; what would be the depth of the well?

Ch. In the first second it would fall 16 feet; in the next 3 times 16 or 48 feet; in the third 5 times 16 or 80 feet; in the fourth 7 times 16 or 112 feet; and in the fifth second 9 times 16 or 144 feet: now, if I add 16, 48, 80, 112, and 144 together, the sum will be 400 feet, which, according to your rule, must be the depth of the well.

Fa. Though your calculation is accurate, yet it was not done as nature effects her operations; for it was not performed in the shortest way.

Ch. I should be pleased to know an easier method: that which I adopted is, however, very simple; because it required nothing but multiplication and addition.

Fa. True: but suppose I had given you an example in which the number of seconds had been fifty instead of five, the work would have taken you an hour, or perhaps more, to have performed it; whereas, by the rule which I am going to give you, it might have been done in half a minute.

Ch. Pray let me have it, Papa. I hope it will be easy to remember.

Fa. It will: nor do I think it can be forgotten after it is once understood. The rule is this: "*the spaces described by a body falling freely from a state of rest, increase as the* SQUARES *of the times increase*:" consequently you have only to square the number of seconds; that is, to multiply the number into itself, and then multiply that again by sixteen feet, the space which it describes in the first second; and you have the answer required. Now try the example of the *well.*

Ch. The square of 5, for the time, is 25, which multiplied by 16 gives 400, just as I brought it out before. Now, if the seconds had been 50, the answer would have been 50 times 50, or 2500, multiplied by 16, which would give 40,000 for the space required.

Fa. I will now ask your sister a question, to try how she has understood the subject. Suppose you observe by this watch that the time of the flight of your brother's arrow is exactly six seconds: to what height does it rise?

Em. This is a different question; because here the *ascent* as well as the *fall* of the arrow is to be considered.

Fa. But you will remember, that the time of the ascent is always equal to that of the descent; for, as the velocity of the descent is generated by the force of gravity, so is the velocity of the ascent destroyed by the same force.

Em. Then the arrow was three seconds only in falling: now the square of 3 is 9, and this multiplied by 16, for the number of feet described in the first second, makes 144 feet, which is the height to which the arrow rose.

Fa. Very right, my dear girl. Now, Charles, if I get you a bow which will carry an arrow so high as to be fourteen seconds in its flight, can you tell me the height to which it will ascend?

Ch. I think I can now answer you without hesitation:—it will be 7 seconds in falling, the square of which is 49, and this multiplied by 16 will give 784 feet, or rather more than 261 yards, for the ascent required.

Fa. If you will now examine the example which you worked by the longer method of calculation, you will see that this rule which I have given you answers every stage of it very completely. In the first second the body fell 16 feet, and in the next 48; these added together make 64, which is the square of the 2 seconds multiplied by 16. The same holds true of the 3 first seconds; for in the third second it fell 80 feet, which added to the 64, give, 144, equal to the square of 3 multiplied by 16. Again, in the fourth second it fell 112 feet, which added to 144, give 256, equal to the square of 4 multiplied by 16: and in the fifth second it fell 144 feet, which added to 256, give 400, which is equal to the square of 5 multiplied by 16. Thus you will find the rule holds good in all cases; viz. "*that the spaces described by bodies falling freely from a state of rest increase as the* SQUARES *of the times increase.*"

Ch. I think I shall not be likely to forget this excellent rule. I can now show my cousin Henry how he may know the height to which his bow will carry.

Fa. Do, by all means; for the surest way of retaining the knowledge we acquire, is by communicating it to our friends and others.

Ch. It is indeed a very pleasant idea, that giving away is the best method of keeping; for, I am sure, the being able to oblige one's friends is a most agreeable feeling.

Fa. I am delighted, my dear Charles, with your generous expressions, and it increases the pleasure I enjoy in your mental improvement, to see such sentiments develop themselves. I have but a word or two more on the subject. Since the *whole spaces* described increase as the squares of the times increase, so also the *velocities* of falling bodies increase in the same proportion; for you know that the velocity must be measured by the space passed through. Thus, if a person travel six miles an hour, and another person travel twelve miles in the same time, the latter will go with double the velocity of the former; consequently the *velocities* of falling bodies increase as the squares of the times increase.

If, now, you compare the spaces described by falling bodies in the *several moments of time taken separately*, and in their order from the beginning of the fall, then they, and consequently their velocities also, are to one another as the odd numbers, 1, 3, 5, 7, 9, 11, 13, &c. taken in their natural order, as you will observe by reflecting on the foregoing examples.

Before we conclude, let me now ask you, Charles, what is said to be the *cause* of the attraction of gravitation, which has occupied our attention in the latter conversations?

Ch. That is a question, dear father, which has puzzled the philosophers of all countries. Many have, I learn, attempted to explain it; but have found themselves bewildered in their own ideas.

Fa. What particulars have you gathered then, generally, on the subject of the attraction of gravitation?

Ch. It appears to me certain, from the phenomena of nature, that, as all heavy bodies near the earth tend to its centre with a force proportionate to the quantity of matter they contain; so the moon also tends to the centre of the earth; and the waters of the sea tend to the centre of the moon; and, in short, both earth and moon, and all the planets and comets tend towards the sun and towards each other.

Fa. With this we will conclude our present conversation.

QUESTIONS FOR EXAMINATION.

How much less would a ball of 20lb. weigh on the top of a mountain 3 miles high than it does on this spot? — By what means could that be ascertained? — How could you find the height of any place? — If a penny-piece is four seconds in falling to the bottom of a well, how deep is that well? — How long would a stone be falling to the bottom of the well at Dover Castle, which is 360 feet deep? — By what law do bodies fall from a state of rest? — If a body takes 11 seconds in falling from a certain place, how high is that place? — Does the ascent of bodies follow a similar law to that of the descent? — How high does an arrow rise, the flight of which is perpendicular, and which takes 10 seconds before it comes again to the ground? — If the flight of an arrow in a perpendicular direction take 16 seconds before it comes to the ground, how high does it go? — Does the rule, with regard to falling bodies, hold good in all cases? — By what law do you calculate the velocities of falling bodies? — How is the velocity of a body measured? — If the several seconds of time be taken separately, how are the spaces of falling bodies estimated?

CONVERSATION IX.

ON THE CENTRE OF GRAVITY.

Father. We are now about to speak of the *Centre of Gravity*, which is that point of a body where its whole weight is concentrated, and upon which, if the body be freely suspended, it will rest; but it will endeavour, in all other positions, to descend to the lowest place it can arrive at.

Ch. All bodies, then, of whatever shape, have a centre of gravity, and if that point is supported, the body will not fall?

Fa. You are perfectly correct, Charles; and if you imagine a line drawn from the centre of gravity of a body towards the centre of the earth, that line is called the *line of direction*, along which every body, not supported, endeavours to fall. If the *line of direction* fall within the base of any body, it will stand; but if it does not come within the base, the body will fall.

If I place the piece of wood, *a*, on the edge of a table, and from a pin at *c*, its centre of gravity, hang a little weight, *d*, the line of direction, *cd*, will fall within the base, and therefore, though the wood leans, yet it will stand secure. But if upon *a*, another piece of wood, *b*, be placed, it is evident that the centre of gravity of the whole will be now raised to *e*, at which point, if a weight be hung, it will be found that the line of direction will fall out of the base, and therefore the body must certainly fall.

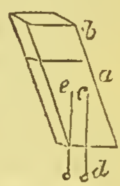


Fig. 7.

Em. I think I now see the reason of the advice which you gave me when we were going up the river in a boat.

Fa. I told you that, if ever you were overtaken by a storm, or by a squall of wind, while you were on the water, never to let your fears so get the better of you as to make you rise from your seat; because, by so doing, you would elevate the centre of gravity, and consequently, as is evident by the last experiment, increase the danger: whereas, if all the persons in the vessel were, at the moment of danger, instantly to slip from their places on to the bottom of the boat, the risk would be exceedingly diminished, because the centre of gravity would

thus be brought lower within the vessel. The same principle is applicable to those who may be in danger of being overturned in land carriages, of whatever construction they may be.

Em. Surely, then, Papa, those stage coaches which have on their roofs immense quantities of luggage, with a dozen or more people besides, cannot be safe for the passengers?

Fa. No, my dear, they are very unsafe; and they would be more so were not the roads in the neighbourhood of London and other large towns remarkably even and good.

Ch. I understand, then, that the nearer the centre of gravity is to the base of a body, the firmer it will stand.

Fa. Certainly: and hence you learn the reason why conical bodies stand so sure on their bases; for their tops being small in comparison with the lower parts, the centre of gravity is thrown very low; and if the cone be upright or perpendicular, the line of direction falls in the middle of the base, which is another fundamental property of steadiness in bodies: for the broader the base, and the nearer the line of direction is to the middle of it, the more firmly does a body stand: but if the line of direction fall near the edge, the body is easily overthrown.

Ch. Is that the reason why a ball is so easily rolled along a horizontal plane?

Fa. It is: for, in all spherical bodies, the base is but a point: consequently the smallest force is sufficient to remove the line of direction out of that base. Hence it is evident that heavy bodies situated on an inclined plane will, while the line of direction falls within the base, slide down the plane; but they will roll when that line falls without the base. The body *a*, will slide down the plane, *de;* but the bodies *b* and *c* will roll down it.

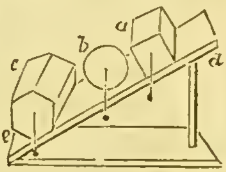


Fig. 8.

Em. I have seen buildings lean very much out of a straight line. Why do they not fall, Papa?

Fa. It does not follow, because a building leans, that the centre of gravity does not fall within the boundary of its base. There is a high tower at Pisa, a city in Italy, which leans fifteen feet out of the perpendicular. Strangers shudder as they pass by it; yet, it is found by experiment that the line of direction falls within the base, and therefore it will stand while its materials hold together.

A wall at Bridgenorth in Shropshire, which I have seen, stands in a similar situation; for so long as a line, *cb*, let fall from the centre of gravity, *c*, of the building, A B, passes within the base, C B, it will remain firm, unless the materials with which it is built go to decay.

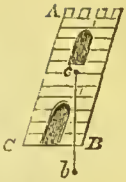


Fig. 9.

Ch. It must be of great use, in many cases, to know the method of finding the centre of gravity in different kinds of bodies.

Fa. There are many easy rules for this with respect to all manageable bodies. I will mention one, which depends on the property which the centre of gravity ever has, of endeavouring to descend to the lowest point.

If a body, *a*, be freely suspended on a pin, *b*, and a plumb line, *bc*, be hung by the same pin, it will pass through the centre of gravity; for that centre is not in the lowest point till it falls in the same line as the plumb line. Mark the line, *bc*; then hang the body up by any other point, as *d*, with the plumb line, *ef*, which will also pass through the centre of gravity, for the same reason as before: and therefore, as the centre of gravity is somewhere in *bc*, and also in some point of *ef*, it must be in the point, *e*, where those lines cross.

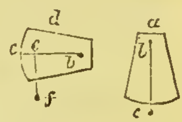


Fig. 10.

QUESTIONS FOR EXAMINATION.

What do you mean by the *centre of gravity?* — Have all bodies a centre of gravity? — What is meant by the *line of direction?* — What should be the line of direction of a body to make it stand? — Look to fig. 7, and explain the subject. — Why is it dangerous to rise up in a boat if the water should be rough? — In a case of danger on the water what is the safest course to take? — Is the same principle applicable to carriages by land? — Is there any danger attaching to stage coaches that are much loaded on the top; and why is it less than might be expected? — Why do not conical bodies stand firm if placed on the point? — What gives stability to bodies? — What is the reason that spherical bodies so easily roll along a horizontal plane? look to fig. 8, and explain the object of it? — Why is it that high buildings, which lean very much, do not fall? — Explain this by means of the figure. — Show me, by means of fig. 10, how to find the centre of gravity of a body.

CONVERSATION X.

OF THE CENTRE OF GRAVITY—*continued.*

Charles. How do those people who have to load carts and wagons with light goods, such as hay, wool, &c., know where to find the centre of gravity?

Fa. Perhaps the generality of them never heard of such a principle: and it seems surprising that, without a knowledge of it, they should, nevertheless, make up their loads with such accuracy as to keep the line of direction in or near the middle of the base.

Em. I have sometimes trembled to pass by the hop-wagons in Kent; and the loads of hay and corn in harvest time.

Fa. And that you might, without incurring any impeachment of your courage, for they are loaded to such an enormous height, that they totter as they go; and it would indeed be impossible for one of them to pass with tolerable security along a road much inclined; for their centre of gravity is removed so high above the body of the carriage, that a little declination on one side or the other would throw the line of direction out of the boundary of the base, beyond the support of the wheels on that side.

Em. When a child falls down, is it because he cannot keep the centre of gravity between his feet?

Fa. It is; but whether the person falling be old or young, it is from the same cause: instances innumerable occur in skating and sliding during the winter season, and if you yourself lean on one side, you will perceive the truth. Hence you learn that a man stands much firmer if his feet be a little apart than if they were close together; for by separating them he increases the base. Hence also the difficulty of sustaining or balancing on your finger a long body, such as a walking-cane, upon a small base.

Ch. How is it that porters are enabled to carry such heavy loads as they do?

Fa. I should tell you that the human body is supported on a base, whose boundaries are the outside edges of the feet, and an imaginary straight line drawn from toe to toe in front, and

from heel to heel behind; and to prevent falling, however a man may be laden, he must keep his centre of gravity above some point in this narrow base: hence we see, if a portion of the body is extended on one side, there must be a counter extension on the other. A porter with a heavy load on his back leans forward; a servant with a loaded tray, as at dinner time, leans backward; and so, stout persons throw back the head, and a nursery-maid, when carrying a child, inclines her body in the opposite direction, that the centre of gravity may be within the boundary of the feet.

Em. How do rope-dancers manage to balance themselves?

Fa. They generally hold a long pole, with weights at each end, across the rope on which they dance, keeping their eyes fixed on some object in a right line with the rope; by which means they know when their centre of gravity declines to one side of the rope or to the other; and thus, by the help of the pole, they throw the weight towards the side which is deficient, and are thus enabled to keep the centre of gravity over the base, narrow as it is. This principle, however, is not confined to rope-dancers: the most common actions of mankind in general are regulated by it.

Ch. In what respects?

Fa. We bend forward, you know, when we go up stairs or rise from our chair; for when we are sitting, our centre of gravity is on the seat, and the line of direction falls behind us: we therefore lean forward to bring the line of direction towards our feet. For the same reason as I have just observed, a man carrying a burthen on his back leans forward; and if he carries it on his breast he leans backward. If the load be placed on one shoulder, he leans to the other. If we slip or stumble with one foot, we naturally extend the opposite arm, making the same use of it as the rope-dancer does of his pole. A very familiar example is that of a butcher on horseback with a loaded basket, which makes him appear more than half off the horse, in order to keep the centre of gravity in its right place.

This property, of the centre of gravity always endeavouring to descend, will account for appearances which are sometimes exhibited to excite our surprise.

Em. What are those, Papa?

Fa. One is, that of a double cone, appearing to roll up two inclined planes, forming an angle with each other; for, as it

rolls, it sinks between them, and thus the centre of gravity is actually descending.

Let a body, *ef*, consisting of two equal cones united at their bases, be placed upon the edges of two straight and smooth rulers, *ab* and *cd*, which at one end meet in an angle at *a*, resting on a horizontal plane, and at the other raised a little above the plane; the body will roll towards the elevated end of the rulers, and appear to ascend; the parts of the cone that rest on the rulers growing smaller as they roll over a larger opening, and thus letting it down, the centre of gravity descends. But you must remember that the height of the planes must be less than the radius of the base of the cone.

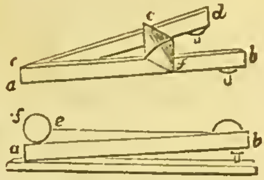


Fig. 11.

Ch. Is it upon this principle that a cylinder is made to roll up hill?

Fa. Yes, it is; but this can be effected only to a small distance. If a cylinder of pasteboard, or very light wood, as *ab*, having its centre of gravity at *c*, be placed on the inclined plane, *de*, it will roll down the inclined plane, because the line of direction from that centre lies out of the base. If I now fill the little hole, *o*, with a plug of lead, it will roll up the inclined plane till the lead gets near the base, where it will lay still; because the centre of gravity is removed by means of the lead from *c*, towards the plug, and therefore is descending, though the cylinder is ascending.

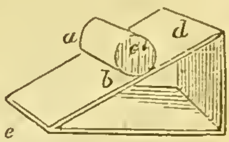


Fig. 12.

Before I close this subject, I will show you another experiment, which, without a knowledge of the principle of the centre of gravity, cannot be understood. Upon this stick, *a*, which, of itself, would fall, because its centre of gravity hangs over the table, *b*, I suspend a bucket, *c*, fixing one end of another stick, *d*, in a notch at *e*, and the other against the inside of the bucket at the bottom. Now you will see that the bucket will in this position be supported, though filled with water: for the bucket being pushed a little out of the perpendicular by the stick *d*, the centre of gravity of the

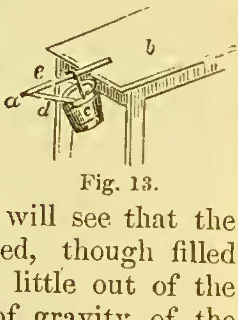


Fig. 13.

whole is brought under the table, and is consequently supported by it.

The knowledge of the principle of the centre of gravity in bodies will enable you to explain the structure of a variety of toys which are put into the hands of children, such as the *little sawyer*, the *rope dancer*, the *tumbler*, *&c.*

Em. How is it, Papa, that there is so much more difficulty in carrying one pail of water than two?

Fa. It is because with only one pail the centre of gravity is thrown on one side, and you find the opposite arm is generally thrown out to bring the centre to its original position; but when there is a pail in each hand, one balances the other, and the centre of gravity remains supported by the feet.

What now have you understood of the centre of gravity?

Ch. It is defined to be a point, about which all the parts of a body or bodies are said to be *in equilibrium.*

Fa. Have you any further remarks to make on this subject, before we proceed to the Laws of Motion?

Ch. I think, Papa, you have explained it sufficiently to make the science as clear as possible to our comprehension.

QUESTIONS FOR EXAMINATION.

Why is there danger attached to wagons, carts, &c. that are loaded very high? — What is the reason that children and others fall? — In what position will a man stand the firmest? — How do rope-dancers manage to balance themselves? — Give me some instances in which people, in general, without knowing it, attend to the direction of the centre of gravity. — How is it that a double cone appears to roll up an inclined plane? — Explain this by fig. 11. — Is there any limit to the height of the planes? — Explain, by fig. 12, how a cylinder is made to roll up a hill. — Tell me, with the assistance of fig. 13, how a bucket is suspended by means of the stick, on the edge of the table.

CONVERSATION XI.

ON THE LAWS OF MOTION.

Charles. Are you now, Papa, going to describe those machines which you call *mechanical powers?*

Fa. We must, I believe, defer that a day or two longer; as I shall give you a few more general principles with which I wish you previously to be acquainted.

In the first place, you must well understand what are denominated the three general laws of motion: the first of which is, that "*a body will continue in its state of rest, or of uniform motion, until it is compelled by some force to change that state;*" and, I may add, the resistance of the body at rest will be equal to the blow struck by the body in motion.

Ch. There is no difficulty in imagining that a body, such as this ink-stand, in a state of rest, must always remain so, if no external force be impressed upon it, to give it motion; but I know of no example which will lead me to suppose, that a body once put into motion would of itself continue so.

Fa. You will, I think, very soon admit the truth of the latter part of the law as well as of the former, although it cannot be established by experiment.

Em. I shall be glad to hear how this is.

Fa. You will not deny that the ball which you strike from the trap, when you are playing, has no more power either to put an end to its motion, or make any change in its velocity, than it has to change its shape.

Ch. Certainly not: nevertheless, in a few seconds after I have struck the ball with all my force, it falls to the ground, and then stops.

Fa. Have you never found any difference in the time that is taken up before a ball comes to rest, in the various places you have ever played, even when struck with the same force?

Ch. Yes: if I am playing on the grass, it rolls not so far as when I play on the smooth gravel.

Fa. You find, also, a like difference, according to the nature of the ground on which you play, when you have your games at marbles.

Ch. Yes, Papa, the marbles run so easily on smooth stones, that we can scarcely shoot with a sufficiently small force.

Em. And I remember that Charles and my cousin were last winter trying how far they could shoot their marbles along the ice in the canal; and they went a prodigious distance, in comparison of that which they would have gone on gravel, or even on smooth pavement.

Fa. By these instances, properly applied, you will be convinced that a body, once put into motion, would go on for ever, if it were not compelled by some external force to change its state.

Ch. I perceive already what you are going to say. It is the rubbing or friction of the marbles against the ground which checks their progress; for on the pavement there are fewer obstacles than on the gravel, and fewer on the ice than on the pavement; hence you would lead us to conclude that, if all obstacles were removed, they might proceed on for ever. But what are we to say of the ball? What stops that?

Fa. You must be aware that, besides friction, there is another and still more important circumstance to be taken into consideration, which affects not only the ball, marbles, &c., but every body that is in motion.

Ch. Yes: it is the *attraction of gravitation.*

Fa. Certainly: for, from what we said when we conversed on that subject, it appears that gravity has a tendency to bring every moving body to the earth; consequently, in a few seconds, your ball must come to the ground from that cause alone. Besides the attraction of gravitation, however, there is the resistance which the air, through which the ball moves, makes to its passage.

Em. That cannot be much, I should think.

Fa. With regard to the ball struck from your brother's trap, perhaps, it is of no great consideration, because the velocity is but small; but in all great velocities, as that of a ball from a musket or cannon, there will be a material difference between the theory and practice, if it be neglected in the calculation. Move your Mamma's riding-whip through the air slowly, and you will observe nothing to hint to you that there is this resisting medium; but if you move it with considerable swiftness, the noise which it occasions will inform you of the resistance it meets with from something or other, and which you will find to be the atmosphere.

Ch. If I now understand you, the force which compels a body in motion to stop, is of three kinds: 1. the *attraction of gravitation;*—2. the *resistance of the air;*—and, 3, the resistance it meets with from *friction.*

Fa. Just so.

Ch. I have now no difficulty in comprehending that a body in motion will not come to a state of rest till it is brought to that state by an external force, acting upon it in some way or other. I have seen a gentleman, skating on very smooth ice, go a great way without any exertion; but where the ice

was rough, he could not go half the distance without making fresh efforts to continue his progress.

Fa. By another instance or two I will further explain this law of motion. Put a basin half filled with water into your little sister's wagon; and when the water is perfectly still, move the wagon; the water, resisting the motion of the vessel or wagon, will at first rise up in the direction contrary to that in which the wagon moves. If, when the motion of the vessel is communicated to the water, you suddenly stop the wagon, the water, in endeavouring to continue the state of motion, rises up on the opposite side.

In like manner, if, while you are sitting quietly on your horse, the animal starts forward, you will be in danger of falling off backward; but if, while you are galloping along, the animal very suddenly stops, you will be liable to be thrown forward.

Ch. This I know by experience: but I was not aware of the reason of it till to-day.

Fa. One of the first, and not the least important, uses of the principles of Natural Philosophy is, that they may be applied to the common concerns of life, and will be found to explain many of its circumstances.

We now come to the *second* law of motion; which is, that "*the change of motion is proportioned to the force impressed, and in the direction of that force.*"

Ch. There is no difficulty in comprehending this: for if, while my cricket-ball is rolling along, I strike it again, it goes on with increased velocity, and that in proportion to the strength which I exert on the occasion; whereas, if, while it is rolling, I strike it back again, or give it a side blow, I change the direction of its course.

Fa. In the same way, gravity and the resistance of the atmosphere change the direction of a cannon-ball from its course in a straight line, and bring it to the ground; and the ball goes to a farther or shorter distance in proportion to the force applied, which in this case would be in proportion to the quantity of powder employed.

The *third* law of motion is, that "*to every action of one body upon another there is an equal and contrary re-action;*" or, briefly, "*re-action is equal to action.*" If I strike this table, I communicate to it the motion of my hand, which you

perceive by the shaking of the glasses; and the table re-acts against my hand, just as much as my hand acts against the table.

If you press one scale of a balance with your finger, to keep it in equilibrium with a pound weight in the other scale, you will perceive that the scale pressed by the finger acts against it with a force equal to a pound, with which the other scale endeavours to descend.

A horse drawing a heavy load is as much drawn back by the load, as he draws it forward.

Em. I do not comprehend how the cart draws back the horse.

Fa. The progress of the horse is impeded by the load, which is the same thing; for the force which the horse exerts would carry him to a greater distance in the same time, were he freed from the incumbrance of the load; and, therefore, as much as his progress falls short of that distance, so much is he, in effect, drawn back by the re-action of the loaded cart.

Again, if you and your brother were in a boat, and if, by means of a rope, you were to attempt to draw another boat to you, the boat in which you were would be as much pulled toward the empty boat as that would be moved toward you: and if the weights of the two boats were equal, they would meet in a point half-way between the two.

If you strike a glass bottle with an iron hammer, the blow will be received by the hammer as well as the glass; and it is immaterial whether the hammer be moved against the bottle at rest, or the bottle be moved against the hammer at rest; yet the bottle will be broken, though the hammer be not injured, because the same blow which is sufficient to break glass is not sufficient to break or injure a mass of iron.

From this law of motion you may learn in what manner a bird, by the stroke of its wings, is able to support the weight of its body.

Ch. Please to explain that, Papa.

Fa. If the force with which it strikes the air below it is *equal* to the weight of its body, then the re-action of the air upwards is likewise equal to it; and the bird, being acted upon by two *equal* forces in contrary directions, will rest between them. If the force of the stroke is *greater* than its

weight, the bird will rise with the *difference* of these two forces; and if the stroke be *less* than its weight, then it will sink with the *difference*.

QUESTIONS FOR EXAMINATION.

What is the first law of motion? — Has a body in motion any power to destroy that motion, or to change its velocity? — What stops a body running on the ground? — And what brings to the earth one that passes through the air? — Is there any other cause besides friction and gravitation that destroys the motion of bodies? — How is the resistance of the air proved? — If a person walking fast is carrying a basin of water, and suddenly stops, what will be the consequence? — If a horse, from standing still, starts suddenly forward, what will happen to the rider? — Can you repeat the second law of motion? — Pray illustrate it by some familiar example. — What changes the direction of a cannon ball? — Upon what does the distance passed depend? — Repeat the third law of motion, and give me an instance in proof of its truth. — How are action and re-action illustrated in the case of a horse drawing a heavy load? — How is this law applicable to the flight of a bird?

CONVERSATION XII.

THE LAWS OF MOTION—*continued.*

Charles. Are those laws of motion which you explained yesterday of great importance in Natural Philosophy?

Fa. Yes, they are; and they should be carefully committed to memory. They were assumed by Sir Isaac Newton as the fundamental principles of mechanics; and you will find them at the head of all books written on these subjects. From these also we are naturally led to some other branches of science, which, though we cannot but slightly mention them, should not be wholly neglected; as they are, in fact, but corollaries to the laws of motion.

Em. What is a corollary, Papa?

Fa. It is nothing more than some truth or consequence clearly deducible from some other truth before demonstrated or admitted. Thus, by the *first* law of motion, *every body must endeavour to continue in the state into which it is put, whether it be of rest, or uniform motion, in a straight line:* from which it follows, as a corollary, that when we see a body move in a curved line, it must be acted upon by at least two forces. *Corollary* is from the Latin *corollarium*, which is

from *corolla*, "a garland," and signified originally a gratuity or donation presented to a person over and above what was strictly his due, and which was generally a *garland*, and given in token of approbation—afterwards it was money: hence it came to imply any present; and, *figuratively*, an additional inference.

Ch. When I whirl round a stone in a sling, what are the forces acting upon the stone?

Fa. There is the force by which the stone would fly off in a right or straight line, were you to let go the string; and there is the force of the hand, which keeps it in a circular motion. Have you never seen a wet mop trundled by a servant? the threads of the mop fly from the centre, but their ends being confined they cannot escape from it; the water, however, not being restrained, flies off in straight lines.

Em. Are there any of these curvilinear motions in nature?

Fa. The moon and all the planets move by a similar law. Take the moon as an instance. It has a constant tendency to the earth by the *attraction of gravitation;* and it has also a tendency to proceed in a right line by that projectile force impressed upon it by the Divine Creator, in the same manner as the stone flies from your hand. Now, by the joint action of these two forces it describes a circular motion.

Em. And what would be the consequence, supposing the projectile force to cease?

Fa. The moon must fall to the earth: and if the force of gravity were to cease from acting upon the moon, it would fly off into infinite space. The projectile force, when applied to the planets, is called the *centrifugal* force, as having a tendency to recede or fly from the centre; and the other force is termed the *centripetal* force, from its tendency to some point as its centre, and, in circular motion, these two forces constantly balance each other.

Ch. And is all this in consequence of the inactivity of matter, by which bodies have a tendency to continue in the same state they are in, whether of rest or motion?

Fa. Yes; and this principle, assumed by Sir Isaac Newton to be in all bodies, he called their *vis inertiæ.*

Centrifugal is derived from two Latin words, *centrum*, "the centre," and *fugio*, "I fly from." *Centripetal* from *centrum*, "the centre," and *peto*, "I seek."

Ch. A few mornings ago, you showed us that the attraction of the earth upon the moon* is 3600 times less than it is upon heavy bodies near the earth's surface. Now, as this attraction is measured by the space fallen through in a given time, I have endeavoured to calculate the space which the moon would fall through in a minute, were the projectile force to cease.

Fa. Well; and how have you found it out?

Ch. A body falls here 16 feet in the first second; consequently, in a minute, or 60 seconds, it would fall 60 times 60 feet, multiplied by 16, that is 3600 feet, which must be multiplied by 16; and, as the moon would fall through 3600 times less space in a given time than a body here, it would fall only 16 feet in the first *minute.*

Fa. Your calculation is accurate. I will recall to your mind the *second* law, by which it appears that *every motion, or change of motion, produced in a body, must be proportional to, and in the direction of, the force impressed.* Therefore, if a moving body receives an impulse in the direction of its motion, its velocity will be increased; if in the contrary direction, its velocity will be diminished; but if the force be impressed in a direction oblique to that in which it moves, then its direction will be between that of its former motion and that of the new force impressed.

Ch. This I know from the observations I have made with my cricket-ball.

Fa. By this second law of motion you will easily understand that if a body at rest receives two impulses at the same time, from forces whose directions do not coincide, it will, by their joint action, be made to move in a line that lies between the direction of the forces impressed.

Em. Have you any machine to prove this satisfactorily?

Fa. There are many such invented by different persons; descriptions of which you will hereafter find in various books on these subjects. But it is easily understood by a figure. If on the ball, *a*, a force be impressed, sufficient to make it move with a uniform velocity to the point *b* in a second of time; and if another force be also impressed on the ball, which alone would make it move to the point *c*, in the same time; the ball,

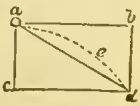


Fig. 14.

* See Conversation IV.

by means of the two forces, will describe the line, *ad*, which is a diagonal of the figure, whose sides are *ac* and *ab*.

Ch. But, how then, is motion produced in the *direction of the force?* According to the second law, it ought to be, in one case, in the direction *ac*, and in the other, in that of *ab*; whereas, it is in that of *ad?*

Fa. Examine the figure a little attentively, carrying this in your mind, that, for a body to move in the *same direction*, it is *not* necessary that it should move in the *same straight line;* but that it is sufficient to move *either* in that line or in any one parallel to it.

Ch. I perceive, then, that the ball, when arrived at *d*, has moved in the direction *ac*, because *bd* is parallel to *ac*, and also in the direction *ab*, because *cd* is parallel to it.

Fa. And in no other possible situation, but at the point *d*, could this experiment be conformable to the second law of motion.

QUESTIONS FOR EXAMINATION.

What is meant by a corollary? — If a body moves in a curved line is it acted upon by more than one force? — What are the forces which act upon a stone whirled round in a sling? — Explain to me by what means the moon is carried about the earth? — What would be the consequence if the projectile force, or the power of gravity, were to cease to act upon the moon? — What do you mean by the *centrifugal*, and *centripetal* forces? — From what do these forces result? — What is meant by the term *vis inertiæ?* — If the projectile force that perpetually acts upon the moon were to cease, through what space would it fall in a minute? — How is the velocity of a body increased, or diminished? — If a body at rest receive at the same instant two impulses, the directions of which do not coincide, in what line will that body move? — Explain this by fig. 14. — Is it necessary for a body to move in the same line, in order that it should move in the same direction?

CONVERSATION XIII.

THE LAWS OF MOTION—*continued.*

Father. If you reflect a little upon what we said yesterday on the second law of motion, you will readily deduce the following corollaries, referring occasionally to the last figure.

1. That if the forces be equal, and act at right angles to one another, the line described by the ball will be the diagonal of

a *square*. But in all other cases, it will be the diagonal of a parallelogram of some kind.

2. By varying the angle, and the forces, you vary the form of your parallelogram.

Ch. Yes, Papa; and I see another consequence; viz. that the motions of two forces acting conjointly in this way are not so great as when they act separately.

Fa. That is true; and you are led to this conclusion, I suppose, from the recollection that, in every triangle, any two sides taken together, are greater than the remaining side; and therefore you infer, and justly too, that the motions which the ball, *a*, must have received, had the forces been applied separately, would have been equal to *a c* and *a b*, or, which is the same thing, to *ac*, and *cd*, the two sides of the triangle, *adc;* but by their joint action, the motion is only equal to *ad*, the remaining side of the triangle.

Hence, then, you will remember that in the *composition*, or adding together of forces, as this is called, motion is always lost: and in the *resolution* of any one force, as *ad*, into two others, *ac* and *ab*, motion is gained.

Ch. Well, Papa; but how is it that the heavenly bodies, the moon for instance, which is impelled by two forces, performs her motion in a circular direction round the earth, and not in a diagonal between the direction of the projectile force and that of the attraction of gravity to the earth?

Fa. Because, in the case just mentioned, there was but the action of a single impulse in each direction; whereas the action of gravity on the moon is continual, and causes an accelerated motion; and hence the line is a curve.

Ch. Supposing, then, that *a* represent the moon, and *ac* the sixteen feet through which it would fall in a second by the attraction of gravity towards the earth, and *ab* represent the projectile force acting upon it for the same time: if *ab* and *ac* acted as single impulses, the moon would in that case describe the diagonal *ad;* but, since these forces are constantly acting, and that of gravity is an accelerating force also, therefore, instead of the straight line *ad*, the moon will be drawn into the curve line *aed*. Do I understand the matter right?

Fa. Yes: and hence you may easily comprehend how, by good instruments and calculation, the attraction of the earth upon the moon was discovered.

The *third* law of motion; viz. that *action and re-action are equal, and in contrary directions,* may be illustrated by the motion communicated by the percussion of *elastic* and *non-elastic* bodies.

Em. What are these, Papa?

Fa. Elastic bodies are those which have a certain spring, by which their parts, upon being pressed inwards by percussion, return to their former state. This property is evident in a ball of wool or cotton, or in sponge when compressed. *Non-elastic* bodies are those which, striking against another, do not rebound, but move together after the stroke.

Let two equal ivory balls, *a* and *b*, be suspended by threads; if *a* be drawn a little out of the perpendicular, and let fall upon *b*, it will lose its motion by communicating it to *b*, which will be driven to a distance, *c*, equal to that through which *a* fell; and hence it appears that the re-action of *b* was equal to the action of *a* upon it.

Fig. 15.

Em. But do the parts of the ivory balls yield by the stroke, or, as you call it, by the percussion?

Fa. They do: for if I lay a little paint on *a*, and let it *touch* *b*, it will make but a very small speck upon it: but if it *fall* upon *b*, the speck will be much larger; which proves that the balls are elastic, and that a little hollow, or dent, was made in each by collision. If, now, two equal soft balls of clay, or glazier's putty, which are non-elastic substances, meet each other with equal velocities, they would stop and stick together at the place of their meeting; as their mutual actions destroy each other.

Ch. I have sometimes shot one marble against another so cleverly, that the second marble has gone off with the same velocity as that with which the first one approached it, and this first marble has remained in the place of the second marble. Are marbles, therefore, as well as ivory, elastic?

Fa. They are. If three elastic balls *b*, *c*, *d*, be hung from adjoining centres, and *d* be drawn a little out of the perpendicular, and let fall upon *c*, then will *d* and *c* become stationary, and *b* will be driven to *a*, the distance through which *d* fell upon *c*.

Fig. 16.

If you hang any number of balls so as to touch each other, and draw the outside one away to a

little distance, and then let it fall upon the others, the ball on the opposite side will be driven off, while the rest remain stationary: so equally is the action and re-action of the stationary balls divided among them. In the same manner, if two are drawn aside and suffered to fall on the rest, the opposite two will fly off, and the others remain stationary.

There is one other circumstance depending upon the action and re-action of bodies, and also upon the *vis inertiæ* of matter, worth noticing. By some authors you will find it largely treated upon: it is this—

If I strike a blacksmith's anvil with a hammer, action and re-action being equal, the anvil strikes the hammer as forcibly as the hammer strikes the anvil: and further—

If that anvil be large enough, I might lay it on my breast, and suffer you to strike it with a sledge hammer with all your strength, without pain or risk of injury; for the *vis inertiæ* of the anvil sufficiently resists the force of the blow: but if the anvil were only a pound or two in weight, your blow would probably kill me, or at least do me some serious injury. This feat is often exhibited at country fairs to many wondering spectators.

It is upon this principle also that the recoil in firing guns and cannons is to be explained, when the re-action is equal to the action: but a heavy cannon by its *vis inertiæ* operates so as to lessen the recoil.

QUESTIONS FOR EXAMINATION.

If two equal forces act upon a body at right angles to one another, what line will be described by that body? — Suppose the forces are not equal and do not act at right angles to one another, what will be the line described? — How do you know that two forces acting conjointly on a body do not produce so great an effect as if they were to act separately? — In what cases is motion lost, and in what others is it gained? — Why do the planetary bodies move in curves? — Explain this by means of the figure. — How is the third law of motion illustrated? — Explain the difference between elastic and non-elastic bodies. —Show me, by a reference to fig. 15, how action and re-action are equal and in contrary directions.— How is it proved that elastic bodies, as ivory balls, yield by percussion? — What would be the consequence of two non-elastic bodies, in motion, meeting each other.— What proof is there that marbles are elastic? Explain to me the intention of fig. 16? — What curious circumstance is there resulting from the *vis inertiæ* of bodies, and from the action and reaction of bodies?

CONVERSATION XIV.

THE MECHANICAL POWERS.

Charles. Will you now, Papa, explain the Mechanical Powers?

Fa. I will: and you must bear in mind *four* things: 1st. that the *power* acting may be either the effort of men or animals, springs, weight, steam, &c.; 2. The resistance to be overcome by the power, is the *weight* or object to be moved; 3. The point about which all the parts of the body move is the prop or *fulcrum;* 4. Observe the respective *velocities* of the power, and of the resisting body. But first, I hope you have not forgotten what the *Momentum* of a body is.

Ch. No, Papa: It is that force of a moving body which is estimated by the weight, multiplied into its velocity.

Fa. May a small body, therefore, have an equal momentum with one much larger?

Ch. Yes, provided the smaller body move much swifter than the larger one, as the weight of the latter is greater than that of the former.

Fa. What do you mean when you say that one body moves swifter, or has a greater velocity than another?

Ch. I mean that it passes over a greater space in the same time. Your watch will explain my meaning. The minute-hand travels round the dial-plate in an hour; but the hour-hand takes twelve hours to perform its course; consequently the velocity of the minute-hand is twelve times greater than that of the hour-hand; because, in the same time, (viz. twelve hours) it travels over twelve times the space that is gone through by the hour-hand.

Fa. But this can be true only on the supposition that the two circles are equal. In my watch, the minute-hand is longer than the other, and consequently the circle described by it is larger than that described by the hour-hand.

Ch. I see at once that my reasoning holds good only in the case where the hands are equal.

Fa. There is, however, a particular point of the longer hand, of which it may be said, with the strictest truth, that it

has exactly twelve times the velocity of the extreme point of the shorter hand.

Ch. That is the point at which, if the remainder were cut off, the two hands would be equal. And, in fact, every different point of the hand describes different spaces in the same time.

Fa. The littte pivot on which the two hands seem to move (for they are really moved by different pivots, one within another) may be called the *centre of motion*, which is a fixed point; and the longer the hand is, the greater is the space described.

Ch. The extremities of the vanes of a windmill, when they are going very fast, are scarcely distinguishable, though the separate parts, nearer the mill, are easily discerned. This is owing to the velocity of the extremities being so much greater than that of the other parts.

Em. Does not the swiftness of the round-abouts which we see at fairs depend on the same principle; viz. the length of the poles upon which the seats are fixed?

Fa. Yes; the greater the distance at which these seats are placed from the centre of motion, the greater is the space which the boys and girls travel for their halfpenny.

Em. Those in the second row then, had a shorter ride for their money than those at the end of the poles.

Fa. Yes; shorter as to space, but the same as to time. In the same way, when you and Charles go round the gravel walk for half an hour's exercise, if he run, while you walk, he will, perhaps, have gone six or eight times round in the same time that you have been but three or four times. Now, as to time, your exercise has been equal; but he may have passed over double the space in the same time.

Ch. How does this apply to the explanation of the mechanical powers?

Fa. You will find the application very easy. Without clear ideas of what is meant by *time* and *space*, it cannot be expected that you could readily comprehend the principles of Mechanics; but let us proceed:

There are six Mechanical powers: the Lever; the Wheel and Axle; the Pulley; the Inclined-plane; the Wedge; and the Screw; and one or more of them will be found employed in every machine; in fact, the great body of mechanism to be

seen in our largest manufactories may be resolved into some one or more of these six powers.

Em. Why are they called Mechanical Powers?

Fa. Because by their means we are enabled *mechanically* to raise weights, move heavy bodies, and overcome resistances, which, without their assistance, could not be done.

Ch. But is there no limit to the assistance gained by these powers? I remember reading of Archimedes, who said that with a place for his fulcrum, he would move the earth itself.

Fa. Human power, with all the wonderful assistance which art can give, is yet very limited, and upon this principle, that "*what we gain in power we lose in time.*" For example: if by your own unassisted strength you are able to raise fifty pounds to a certain distance in one minute, and if by the help of machinery, you wish to raise 500 pounds to the same height, you will require ten minutes to perform it: thus you increase your power ten-fold, but it is at the expense of time; or, in other words, you are enabled to do, with one effort, in ten minutes, that which you could have done in ten separate efforts in the same time.

Em. The importance of mechanics, then, is not so great as we might imagine it to be at first sight; as there is no real gain of force acquired by the mechanical powers.

Fa. You must consider that, although there be not any actual increase of force gained by these powers; the advantages which men derive from them are inestimable. Suppose, for example, that several small weights, manageable by human strength, are to be raised to a certain height, it may be fully as convenient to elevate them one by one as to take the advantage of the mechanical powers, in raising them all at once; because, as we have shown, the same time will be necessary in both cases: but suppose you have a large block of stone, or a ton weight, to carry away, or a weight still greater, what would you do?

Em. I did not give that a thought.

Fa. Bodies of this kind cannot be separated into parts proportionate to human strength without immense labour, nor, perhaps, without rendering them unfit for those purposes to which they are to be applied. Hence, then, you perceive the great importance of the mechanical powers; by the use of

which a man is enabled to manage with ease a weight many times greater than himself.

Ch. I have, in fact, seen a few men, by means of pulleys, and seemingly with no very great exertion, raise an enormous oak into a timber-carriage, in order to convey it to its destination.

Fa. A very excellent instance, Charles: for if the tree had been cut into such pieces as could have been managed by the natural strength of these men, it would not have been worth carrying away for any purpose which required an extended length.

Em. I now perceive it clearly. What is a fulcrum, Papa?

Fa. It is the *fixed point*, or prop, round which the other parts of a machine move. It is a Latin word, meaning a *prop*.

Ch. The pivot, upon which the hands of your watch move, is a fulcrum, is it not, Papa?

Fa. Certainly it is: and you remember we called it also the centre of motion. The rivet of these scissars is also a fulcrum.

Em. Is that a fixed point, or prop?

Fa. Undoubtedly, as it regards the two parts of the scissars; for that always remains in the same position, while the other parts move about it. Again; take the poker, and stir the fire, now that part of the bar on which the poker rests is a *fulcrum;* for the poker moves upon it as a centre.

It must be borne in mind, that a greater force, the weight, can under no circumstances be supported by a less, the power; the fact is, that by the contrivance of the lever, a portion of the resistance is made to be borne by the fulcrum, the whole of it being divided between that point and the point of application of the power.

Are you now, my children, satisfied with the foregoing explanation of the Laws of Motion?

Ch. Yes, Papa; and besides what you have there set forth, experience teaches us that it requires the same force to destroy motion as to produce it: therefore, all bodies are inactive, so that they cannot move unless impelled, or stop unless by some force impressed on them.

Fa. Is motion perpetual?

Ch. Yes; as regards itself; but no motion contrived by art can be perpetual, on account of the resistance of the medium.

Fa. Are the centripetal and centrifugal forces always equal?

Ch. Yes, for as they act in contrary directions, they destroy each other's effect; so that neither body is suffered to fly off nor fall in, but is continued on its own proper and acquired orbit.

Fa. Then you account for the continued motions of the heavenly bodies in this way?

Ch. Such, I find, is the opinion established by Science. The moon revolves about the earth from the same causes that the earth and other planets revolve about the sun; that is, by means of a *projectile* force, and a *centripetal* force tending to the centre of the earth.

Fa. Does this apply to all other kinds of motion?

Ch. The same principles certainly apply to all kinds of motion.

Fa. In our Ninth Conversation you were informed of the effect produced by motion on a person riding on horseback. Have you ever heard of any other example of this operation of the laws of motion?

Ch. I recollect a circumstance in point, related to me some time ago by a friend, who was present when it happened. But I never reflected till now how much it illustrates the present subject. It is this:—A troop of yeomanry cavalry had been raised in a northern district during the late war, consisting of farmers, butchers, &c., as is usual, and had become tolerably expert in their exercise; but their horses had not been sufficiently trained to execute any manœuvres with honour to themselves. Notice having been giving that the reviewing officer of the district would pay them a visit on a certain day, for the purpose of inspection, the volunteers solicited the Colonel of a cavalry regiment, stationed in neighbouring barracks, to lend them, for the important day, as many regularly trained horses as would mount them all for the review. The Colonel, *smiling*, complied. The yeomen were mounted. Manœuvres began, and went on tolerably well till a charge was sounded. The gallant troop rushed on with great rapidity, sword in hand, elate with pride in their own dexterity, when, lo! the bugle suddenly sounded a halt. The dead stop of the horses at this signal, so different from anything their riders had been before accustomed to, threw

most of them several feet over their heads, to the no small humiliation of the yeomanry. Fortunately, they reeeived but little personal injury. These poor fellows had therefore sueh a *lesson* on the *Laws of Motion* as, I suppose, they will never forget.

Fa. I am glad to find your memory so exeellent; but we will now revert to our present Leeture: you have in this become aequainted with the simple meehanical powers, and learned their names. What have you to remark thereon ?

Ch. I pereeive, plainly, that they are ealculated to perform what the strength of any animal eould not effeet without them; but I must eonfess I have not understood mueh of the prineiples on whieh they aet; besides, nothing has been said in respeet of the *motion of weight.*

Fa. What have you gathered from the authors you have read on that point?

Ch. I understand that the body whieh is moved, or hindered from moving, is the *weight.* That whieh moves or sustains the weight is ealled the *power.* By the action of the weight we are not to understand the motion of its eentre of gravity in a horizontal line, nor the eireular motion of the parts about the eentre of gravity: for, in both these eases the gravitation of the body is no impediment to its motion. The motion of the weight is merely the aseent or deseent of its eentre of gravity.

But are there not, Papa, distinct eentres to be eonsidered in eonnexion with Meehanies in general?

Fa. Yes; there are three eentres. First, the *centre of magnitude* of a body, whieh is a point taken as nearly as possible at an equal distanee from all the outward parts. Seeondly, the *centre of motion* of a body, whieh is any point whereon the body may rest, or about whieh it may move. Thirdly, the *centre of gravity* of a body, whieh is a point whereon all the parts of the body balanee eaeh other; so that if this point be made the eentre of motion, the body may be plaeed and eontinued at rest in any situation.

Ch. Can any body stand or retain its position upon either a horizontal or inelined plane suspended, unless a perpendieular proceeding from the eentre of gravity fall within the base?

Fa. No. In all suspended bodies at rest upon any centre

of motion, the centre of gravity is either directly over or directly under the centre of motion.

QUESTIONS FOR EXAMINATION.

What do you mean by the momentum of a body?—Do you know how to make the *momenta* of unequal bodies, equal?—What is meant by one body having a greater velocity than another?—What familiar example will illustrate it?—Does every part of the minute hand of a watch or clock travel twelve times faster than the hour hand?—What is meant by the centre of motion of a watch?—What parts of the vanes of a windmill move the faster?—Why are some parts of the vanes of a mill in quick motion more distinguishable than others?—Can you give me another instance or two on this subject?—Is it necessary to have clear ideas with regard to *time* and *space?*—How many mechanical powers are there?—Why are they so called?—What limits the assistance gained by these powers?—Explain what you mean by the phrase, that "what we gain in power we lose in time."—How are the advantages of the mechanical powers set forth?—What is meant by a fulcrum?—What is the fulcrum of a watch?—Why is the pivot on which scissars move called a fulcrum?—When you stir the fire with a poker what forms the fulcrum?

CONVERSATION XV

OF THE LEVER.

Father. We will now consider the *Lever*, which is generally called the *first mechanical power.*

The *lever* is any inflexible bar of wood, iron, or other material, which serves to raise weights, while it is supported at a point by an immoveable prop or *fulcrum*, on which, as the centre of motion, all the other parts turn.—*ab*, will represent a *lever*, and the point *c*, the *fulcrum* or centre of motion; and the two parts of the lever divided by the fulcrum, are called its arms. Now, it is evident, if the lever turn on its centre of motion, *c*, so that *a* comes into the position *e;* *b* at the same time must come into the position *d*. If both the arms of the lever be equal, that is, if *ac* is equal to *bc*, there is no advantage gained by it; for they pass over equal spaces in the same time: and, according to the fundamental principle already laid down (p. 55) "*as power is gained, time must be lost:*" therefore, no time being lost by a lever of this kind, there can be no power gained.

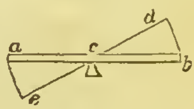


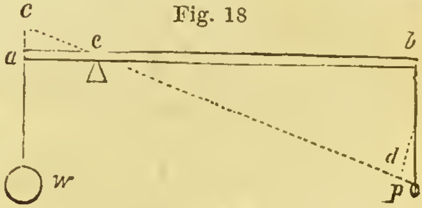
Fig. 17.

Ch. Why, then, is it called a mechanical power?

Fa. Strictly speaking, perhaps, it ought not to be so considered; but it is usually reckoned as one, and has the *fulcrum* between the weight and the power, which is the distinguishing property of levers of the first kind: and when the fulcrum is exactly the middle point between the weight and power, it forms the common balance; to which, if scales be suspended at *a* and *b*, it is fitted for weighing all sorts of commodities. The point of suspension is the fulcrum or centre of motion; scales for weighing heavy bodies are sometimes balanced upon this fulcrum instead of being suspended.

Em. You say it is a lever of the *first* kind. Are there several sorts of levers?

Fig. 18

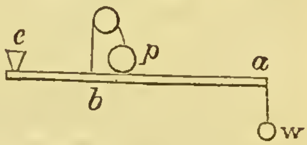


Fa. Yes; there are three sorts: some persons reckon four: the fourth, however, is but a bended one, of the first kind. A lever of the *first* kind, has the *fulcrum between* the weight and the power.

Fig. 19.

The *second* kind of lever has the fulcrum at one end, the power at the other, and the *weight between* them.

Fig. 20.



In the *third* kind the *power is between* the fulcrum and the weight.

> " Of Levers' powers the different sorts are three;
> The *first* in steel-yards and in scales you see;
> The best, a *second*, is the miller's lift,
> Where *power* and *fulcrum* to each end you shift;
> And in the *third* the worst of all, my friend,
> You find the *weight* and *fulcrum* at each end."

Let us take the lever of the first kind (fig. 18), which, if it be moved into the position *cd*, by turning on its fulcrum, *e*, it is evident that while *a* has travelled over the short space *ac*, *b* has travelled over the greater space *bd;* which spaces are to one another exactly in proportion to the length of the arms *ae* and *be*. If, therefore, you apply your hand first to the point *a*, and afterwards to *b*, in order to move the lever

into the position *cd*, using the same velocity in both cases, you will find that the time spent in moving the lever, when the hand is at *b*, will be as much greater as that spent when the hand is at *a*, as the arm *be* is longer than the arm *ae;* but then the exertion required will, in the same proportion, be less at *b* than at *a*.

Ch. The arm *be* appears to be four times the length of *ae*.

Fa. Then it is a lever which gains power in the proportion of four to one: that is, a single pound weight applied to the end of the arm *be*, as at *p*, will balance four pounds suspended at *a*, as *w*.

Ch. I have seen workmen move large pieces of timber to very small distances by means of a long bar of wood or iron. Is that a lever?

Fa. Yes: they force one end of the bar, termed a crow-bar, under the timber, and then place a block of wood, stone, &c., beneath, as near the same end of the lever as possible, for a fulcrum, applying their own strength to the other. Power is gained in proportion as the distance from the fulcrum to the part where the men apply their strength is greater than the distance from the fulcrum to the end which is under the timber.

Ch. It must be very considerable; for I have seen two or three men move a tree in this way, of several tons weight, I should think.

Fa. That is not difficult: for, supposing a lever to gain the advantage of twenty to one, and a man by his natural strength being able to move but a hundred weight, he will find that by a lever of this sort he can move twenty hundred weight, or a ton; for single exertions, however, a strong man can put forth a much greater power than is sufficient to remove a hundred weight! and some levers are in use, by which a still more considerable advantage is gained than that of twenty to one.

Ch. I think you said, the other day, that the common steel-yard is a lever.

Fa. I did so: the short arm *ac* is, by an increase of size, made to balance the longer one *bc*, and from *c*, the centre of motion, the divisions or graduated marks must commence. Now, if *bc* be divided into as many

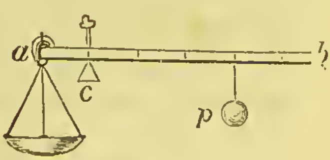


Fig. 21.

parts as it will contain, each equal to *ac*, a single weight, as a pound, *p*, will serve for weighing anything as heavy as itself, or as many times heavier as there are graduated marks or divisions in the arm *c*. If the weight *p* be placed at the division 1 in the arm *bc*, it will balance one pound in the scale at *a*: if it be removed to 3, 5, or 7, it will balance 3, 5, or 7 pounds in the scale; for these divisions being respectively 3, 5, or 7 times the distance from the centre of motion *c* that *a* is, it becomes a lever, which gains advantage, at those points, in the proportions of 3, 5, and 7. If, now, the intervals between the divisions on the longer arm be subdivided into halves, quarters, &c., any weight may be accurately ascertained even to halves, or quarters of pounds, &c. In the steel-yard, the hook by which it is suspended is its fulcrum or prop.

On the same principle is the *See-saw*: when two boys ride see-saw on a plank drawn over a log of wood, the plank is a lever, the log the fulcrum, and one boy is the power, and the other the weight or resistance. If the boys are of equal weight, the plank must be supported in the middle; to make the two arms equal; if they differ in weight the plank must be drawn over the prop to make the arms unequal, and the lightest boy placed at the end of the longest arm, in order that the greater velocity of his motion may make up for the greater weight of his companion, so that their momenta may be equal; and each as he comes alternately to the ground may be called the power.

QUESTIONS FOR EXAMINATION.

What is meant by a lever, and for what is it used? — Explain by means of *fig.* 17 its mode of action. — How many sorts of levers are there? — How is the fulcrum situated in the lever of the first kind? — How in that of the second? — How in the third? — Repeat the lines descriptive of the lever? — In what proportion are the spaces described by the arms of a lever? — Can you explain this by referring to fig. 18? — What power does a lever gain whose two arms are as 9 to 3? — How is it that an iron crow in moving timber or stone, acts upon the principle of a lever? — Explain by fig. 19, how it is that the common steel-yard, made use of by the butcher, is a lever.

CONVERSATION XVI.

THE LEVER—*continued.*

Emma. What advantage has the steel-yard, which you described in our last conversation, over a pair of scales?

Fa. It may be much more readily removed from place to place, and requires no other apparatus than a single weight for all the purposes to which it can be applied. Sometimes the arms are not of equal weight. In that case the weight *p* must be moved along the arm *b c*, till it exactly balances the other arm without a weight; and in that point a notch must be made, marking over it a cypher 0, from which the divisions or graduated marks must commence.

Ch. Is there great accuracy required in the manufacture of instruments of this kind?

Fa. Yes. Of such importance is it to the public that there should be no error or fraud by means of false weights, or false balances, that it is the business of certain public officers to examine, at stated seasons, the weights, measures, &c., of every shopkeeper in the land. Yet it is to be feared that, after all precautions, much fraud is practised upon the unsuspecting.

Em. One day last summer I bought, as I supposed, a pound of cherries at the door: but Charles thinking they did not weigh a pound, we tried them in your scales, and found but twelve ounces, instead of a pound: and yet the scale went down as if the man had given me full weight. How was that managed?

Fa. It might be done in many ways: by short weights, or by the scale in which the fruit was put being made in some way heavier than the other; but fraud may be practised with good weights and even scales, by making that arm of the balance, on which the weights hang, shorter than the other; for then a pound weight will be balanced by as much less fruit than a pound as that arm is shorter than the other. This was probably the method by which you were cheated.

Em. By what method could I have discovered this cheat?

Fa. The scales, when empty, are exactly balanced: but when loaded, though still in equilibrium, the weights are unequal, and the deceit may instantly be discovered by changing the weight to the contrary scale. I will give you a rule to find the true weight of any body by such a false balance. The reason of the rule you will understand hereafter. "*Find the weight of the body by both scales, multiply them together, and then find the square root of the product, which is the true weight.*"

Ch. Let me see if I understand the rule. Suppose a body to weigh 16 ounces in one scale, and in the other 12 ounces and a quarter; if I multiply 16 by 12 and a quarter, I get the product 196; the square root of which is 14: for I find 14 multiplied into itself gives 196; the true weight of the body therefore is 14 ounces.

Fa. That is just what I meant. To the lever of the first kind may be referred many common instruments, such as scissars, shears, sugar-nippers, pincers, snuffers, the hand-pike, toothed-hammer, pump-handle, &c., which are made of two levers, acting contrary to each other.

Em. The rivet where the two levers are screwed together is the fulcrum or centre of motion; the hand the power used; and whatever is to be cut is the resistance to be overcome; therefore the longer the handles, and the shorter the points of the scissars, the more easily will they cut; hence when pasteboard, or any hard substance is to be cut, we use that part of the scissars nearest the screw or rivet.

Ch. A poker stirring the fire is also a lever; for the bar is the fulcrum, the hand the power, and the coals the resistance to be overcome.

Fa. We now proceed to levers of the *second* kind, in which the fulcrum *c* (fig. 19,) is at one end, the power *p* at the other end *b*, and the weight to be raised, *w*, is somewhere between the fulcrum and the power.

Ch. And how is the advantage gained to be estimated in this lever?

Fa. By looking at the figure you will find that power or advantage is gained in proportion as the distance of the power *p* from the fulcrum is greater than the distance of the weight *w*.

Ch. Then, if the weight is suspended at one inch from the fulcrum, and the power acts at five inches from it, the power gained is five to one; or one pound at *p* will balance five at *w*?

Fa. It will: for you perceive that the power passes over five times as great a space as the weight; or, while the point *a*, in the lever, moves over one inch, the point *b* will move over five inches.

Em. What things in common use are to be referred to the lever of the *second* kind?

Fa. The most common and useful of all things. Every door, for instance, which turns on hinges, is a lever of this sort. The hinges may be considered as the fulcrum or centre of motion; the whole door is the weight to be moved; and the power is applied to that side on which the handle is usually fixed.

Em. Now I see the reason why there is considerable difficulty in pushing open a heavy door, if the hand is applied to any part near the hinges; although it may be opened with the greatest ease in the usual method.

Ch. This sofa, with my sister upon it, represents a lever of the second kind. Does it not, Papa?

Fa. Certainly; if, while she is sitting upon it, in the middle, you raise one end, while the other remains fixed as a prop or fulcrum. Similar to this is the *wheel-barrow;* in which the axis of the wheel is the fulcrum, the load and barrow, the weight or resistance, and the force of the labourer, the power. To this kind of lever may be also referred nut-crackers, oars, rudders of ships; and those cutting knives with one end fixed in a block, used for cutting chaff, drugs, and wood for various uses; also lemon and cork squeezers, &c.

Em. I do not see how oars and rudders are levers of this sort.

Fa. The boat is the weight to be moved, the water is the fulcrum, and the waterman at the handle of the oar the power; so that the force with which the boat is impelled, is to that exerted by the rower, as the distance from the middle of the blade to the point where he grasps the oar, is to the distance from the same point, to the side of the boat. The masts of ships are also levers of the second kind; for the bottom of the vessel is the fulcrum, the ship the weight, and the wind acting against the sail is the moving power.

The knowledge of this principle may be useful in many situations and circumstances of life. If two men, unequal in strength, have a heavy burden to carry on a pole between them, the ability of each may be consulted by placing the burden as much nearer to the stronger man as his strength is greater than that of his partner.

Em. Which would you call the prop in this case ?

Fa. The stronger man: for the weight is nearer to him; and the weaker would then be considered as the power. Again, two horses may be so yoked to a carriage, that each shall draw a part proportioned to his strength, by dividing the beam in such a manner, that the point of *traction*, or drawing, may be as much nearer to the stronger horse than to the weaker, as the strength of the former exceeds that of the latter.

We will now describe the *third* kind of lever, the great object of which is to produce great velocity by an expenditure of force. In this, the prop or fulcrum *c* (fig. 20.) is at one end, the weight *w*, at the other, and the power *p* is applied at *b*, somewhere between the prop and the weight.

Ch. In this case, the weight, being farther from the centre of motion than the power, must pass through more space than the former.

Fa. And what is the consequence?

Ch. That the power must be greater than the weight; and as much greater as the distance of the weight from the prop or fulcrum exceeds the distance of the power from the prop; hence, to balance a weight of *three* pounds at *a*, there will be required the exertion of a power, *p*, acting at *b*, equal to *five* pounds.

Fa. Since, then, a lever of this kind is a disadvantage to the moving power, it is but seldom used, and only in cases of necessity; such as in that of a ladder, which, being fixed at one end against a wall or other obstacle, is, by the strength of a man's arm, raised into a perpendicular position. But the most important application of this third kind of lever is manifest in the structure of the limbs of animals, particularly in those of mankind. The fulcra are the joints, the power is supplied by muscles through the intervention of tendons, attached very near the fulcra, and the direction of their tensions very oblique to the direction of the limb. Let us take

the arm as an instance. When we lift a weight by the hand, it is principally effected by means of a muscle coming from the shoulder blade, and terminating about one-tenth as far below the elbow as the hand is. The elbow being the centre of motion, round which the lower part of the arm turns, according to the principle just laid down, the muscle must exert a force ten times as great as the weight that is raised. At first view, this may appear a disadvantage; but what is lost in power is gained in velocity; and thus the human figure, by a wise Providence, is better adapted to the various functions it has to perform.

Fa. Can you tell me what people, in ancient times, used the steel-yard instead of scales?

Ch. The Romans, according to all accounts, used it in common; indeed, we see it in the *bas-reliefs* on their buildings, held by a figure of Justice, in the same manner as the scales are held by a similar figure on modern edifices. The steel-yard is known to us, therefore, by the term, *Statera Romana.* But do you not think, Papa, that the scales are better calculated to weigh with precision?

Fa. I doubt not that they are preferable; for an artful person may, by a slight touch of the lever of the steel-yard, deceive us very much in the weight.

Ch. True: but cannot deceptive tricks be exercised also with the scales?

Fa. Undoubtedly; and the poor are often cheated by too refined a knowledge of retailers in the use of the balance. The only way to take that power out of their hands effectually, would be an act of the Legislature, giving every buyer the right of putting the weight into which ever scale he should prefer. I am gratified to find that you exercise your mind in the cause of humanity, as well as in that of knowledge; but we must close our present conversation.

QUESTIONS FOR EXAMINATION.

In practice is there any advantage in a steel-yard over a pair of scales?— How is the beam of a steel-yard divided? How can fraud be practised in weighing out commodities, when the scales are even and the weights accurate? — What method would lead to a detection of this sort of cheat? — What is the rule to find the true weight of a body by means of a false balance? — Apply this rule by supposing a body to weigh 20 ounces in one scale, and in the other only 15 ounces. — What common instruments are to be referred to the

lever of the first kind? — Why are they so referred? — Show me by means of fig. 19, the action of a lever of the second kind, and what advantage is gained by it? — What things in common use are to be referred to the lever of the second kind? — What causes the difficulty of moving a heavy door, when the hand is applied to that part next to the hinges? — Mention some other things that act as levers of the second kind. — Can the knowledge of this principle be made practically useful in other instances? — How is the case of two men of unequal strength carrying a burden, referable to the principle of a lever of the second kind? — Is the same principle applicable to the horse drawing a carriage? — Describe by fig. 20, the lever of the third kind. — What proportion must the power bear to the weight in levers of this kind? — Is any advantage gained by this lever as a moving power? In what cases is it used? — What is the most important application of the principle of this lever?

CONVERSATION XVII.

OF THE WHEEL AND AXLE.

Father. Well, Emma, do you understand the principle of the lever, which we discussed so much at large yesterday?

Em. I think so, Papa: the lever gains advantage in proportion to the space passed through by the acting power; that is, if the weight to be raised be at the distance of one inch from the fulcrum, and the power is applied nine inches distant from it, then it is a lever, which gains advantage as 9 to 1; because the space passed through by the *power* is nine times greater than that passed through by the weight; and, therefore, what is lost in time, by passing through a greater space, is gained in power.

Fa. You recollect also what the different kinds of levers are, I hope.

Em. I shall never see the fire stirred without thinking of a simple lever of the *first* kind; and my scissars will frequently remind me of a combination of two levers of the same sort; the opening and shutting of the door, will prevent me from forgetting the nature of the lever of the *second* kind; and, I am sure that I shall never see a workman raise a ladder against a house without recollecting the *third* sort of lever. Besides, I consider that a pair of tongs is a lever of this kind.

Fa. You are right; for the fulcrum is at the joint, and the power is applied between that and the parts used in taking up coals, &c. So, also, is the treddle of a turning-lathe, and the

shears used by sheep-shearers, and sugar-tongs. Can you, Charles, tell me, how the principle of *momentum* applies to the lever?

Ch. The *momentum* of a body is estimated by its weight, multiplied into its velocity; and the velocity must be calculated by the space passed through in a given time. Now, if I examine the lever, in the engravings, p. 60, and consider it as an inflexible bar turning on a centre of motion, it is evident that the same time is used for the motion both of the weight and the power; but the spaces passed over are very different; that which the power passes through, being as much greater than that passed by the weight, as the length of the distance of the power from the prop or fulcrum is greater than the distance of the weight from the prop; and the velocities being as the spaces passed in the same time, must be greater in the same proportion. Consequently, the velocity of *p*, the power, multiplied into its weight, will be equal to the smaller velocity of *w*, multiplied into its weight; and thus, their momenta being equal, they will balance one another.

Fa. This applies to the *first* and *second* kind of lever. What do you say to the *third?*

Ch. In the third, the velocity of the power *p*, (fig. 20,) being less than that of the weight *w*, it is evident, in order that their momenta may be equal, that the weight acting at *p* must be as much greater than that of *w* as *a c* is less than *b c;* and then they will be in equilibrium.

Fa. We come now to the second Mechanical power, viz., the *Wheel and Axle*, which gains power in proportion as the circumference of the wheel is greater than that of the axle. This machine may be referred also to the principle of a perpetual Lever: *ab* is the wheel, *c d* its axle; and if the circumference of the wheel be eight times as great as that of the axle, then a single pound, *p*, will balance a weight, *w*, of eight pounds. It is principally used in the elevation of weights.

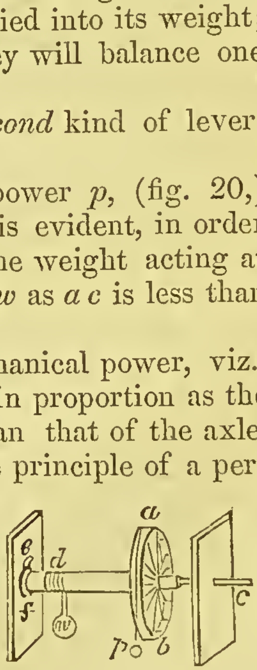


Fig. 22.

Ch. Is it by an instrument of this kind that water is drawn from those deep wells so common in many parts of the country?

Fa. It is; but, as in most cases of this kind, only a single

bucket is raised at once, there requires but little power in the operation, and therefore, instead of a large wheel, as *a b*, an iron handle, called a *winch*, fixed at *c*, is employed, which, you can well imagine, by its circular motion, to answer the purpose of a wheel. This construction is called a *windlass.*

Ch. I can fancy the iron shaft attached to the handle to represent the spoke of a wheel, and I once raised some water by a machine of this kind, and found that, as the bucket ascended nearer the top, the difficulty increased.

Fa. That must always be the case where the wells are so deep as to cause, in the ascent, the rope to coil more than once round the length of the axle; because the advantage gained is in proportion as the circumference of the wheel is greater than that of the axle; so that, if the circumference of the wheel be 12 times greater than that of the axle, one pound applied at the former will balance 12 hanging at the latter; but, by the coiling of the rope round the axle, the *difference* between the circumference of the wheel and that of the axle continually diminishes, the advantage consequently gained is less every time a new coil of rope is wound on the whole length of the axle. This explains why the difficulty of drawing the water or any other weight increases as it ascends nearer the top.

Ch. Then, by diminishing the axle, or by increasing the length of the handle, or size of the wheel, advantage is gained?

Fa. Yes; by either of those methods you may gain power; but it is very evident that the axle cannot be diminished beyond a certain limit without rendering it too weak to sustain the weight; nor can the handle be managed if it be constructed on a scale much larger than what is commonly used.

Ch. We must, therefore, have recourse to the wheel, with spikes standing out of it at certain distances from each other, to serve as levers.

Fa. You may by this means increase your power; but it must be at the expense of time; for you know that a simple handle may be turned several times while you are pulling the wheel round once. The conical wheel of a watch, called the *fusee*, is made in the shape of a cone, so that its radii may increase exactly in the proportion in which the power diminishes. When the watch is just wound up the fusee acts by its smallest radius, and as the spring or power weakens, the

greatest radius comes into operation. To the principle of the *wheel and axle* may be referred the grindstone, the capstan of ships, and windlass, and all those numerous kinds of cranes which are to be seen at the different wharfs on the banks of the rivers and canals, &c.

Ch. What kind of a thing is a capstan, Papa?

Fa. A capstan is of similar construction to the windlass, except that the axle or cylinder round which the rope coils is not placed horizontally but vertically; and the power is applied by means of a series of levers placed round it at equal distances in the direction of radii.

Ch. I have seen a crane consisting of a wheel large enough for a man to walk in.

Fa. In this the weight of the man, or men (for there are sometimes two or three), is the moving power: for, as the man steps forward, the part upon which he treads becomes the heaviest, and consequently descends till it be the lowest. On the same principle, you may see, at the door of many birdcage-makers, a bird, which, by its weight, will give a wicker cage a circular motion. Now, if there were a small weight suspended to the axle of the cage, the bird, by its motion, would draw it up: for, as it hops from the bottom bar to the next, its *momentum* causes that to descend; and thus the operation is performed, both with regard to the cage and to those large cranes which you have seen: and so in squirrel cages.

In like manner *tread-wheels* on a very large construction have been employed in our prisons to give motion to the axle; the strength of the legs, combined with the weight of the body, giving much greater power than the arms.

Em. Is there no danger if a man happens to slip?

Fa. If the weight be very great, a slip with the foot may be attended with very dangerous consequences. To prevent which, there is generally fixed, at one end of the axle, a little wheel, *g* (fig. 22,)* called a racket wheel, with a catch *h*, to fall into its teeth: this will, at any time, support the weight, in case of an accident. Sometimes, instead of men walking within the great wheel, cogs are set round it on the outside, and a small trundle wheel to be turned by a winch is made to work in the cogs.

* See engraving, p. 69.

Ch. Are there not other kinds of cranes, in the use of which there is no such danger as you have been describing?

Fa. You should know, my dear children, that the crane is a machine of so much importance to the commercial concerns of this country that alterations and improvements in it are continually offered to the public. When we go to the library I will show you, in the tenth volume of the "Transactions of the Society for the Encouragement of Arts and Sciences," an engraving of a safe, and, I believe, very excellent crane, invented by Mr. James White, who possessed a most extraordinary genius for mechanics.

Ch. But you said that this mechanical power might be considered as a lever of the first kind.

Fa. I did: and if you imagine the wheel and axle (fig. 22,) to be cut through the middle in the direction *a b*, *f g b* (fig. 23,) will represent a section of it: *a b* is a lever, whose centre of motion is *c;* the weight *w*, sustained by the rope *a w*, is applied at the distance *c a* the radius of the axle; and the power *p*, acting in the direction *b p*, is applied at the distance *c b*, the radius or spoke of the wheel; therefore, according to the principle of the lever, the power will balance the weight when it is as much less than the weight as the distance *c b* is greater than the distance of the weight *a c*. You cannot but have admired in mills and factories, the immense wheel whose revolution puts the whole machinery into motion, and which requires one or two horses to turn it. sometimes a stream of water effects the purpose, as in a water-mill; sometimes the wind, as in the windmill; but the greatest power of all is the steam-engine, and it is indeed the most efficient and most convenient. We shall have occasion to speak of it more fully by and by.

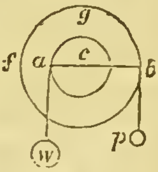


Fig. 23.

Ch. Are there not many improvements made in the wheel and axle?

Fa. Yes, there are; I have observed many new machines on this construction in the docks and on board ships. These improvements, however, can only be made in the execution and power of the machinery; as the principles cannot be changed.

Ch. You told us in the last conversation that the wheel and axle gains power in proportion as the circumference of

the wheel is greater than that of the axle. Does not the thickness of the rope have some influence upon it?

Fa. If the thickness of the rope be considerable, its semi-diameter must be added both to the radius of the wheel and to the radius of the axle. When the rope begins to cover the axle a third time, five times the semi-diameter of the rope must be added to the radius of the axle.

Ch. In that case, if the machine is to be worked always with the same velocity, the power must be increased every time the rope recedes from the axle?

Fa. Yes, undoubtedly.

QUESTIONS FOR EXAMINATION.

Explain the general principles of the lever, and what the circumstances are that will prevent you from forgetting the properties of each?—How does the principle of *momentum* apply to the lever?—What is the second mechanical power, and how does it gain power?—Look to figure 22 and show me how the *wheel and axle* is to be referred to the principle of the lever? — To what purpose is the wheel and axle applied?—Why in deep wells does the bucket appear heavier as it approaches the top than lower down? — By what means is advantage gained? — What is the limit to the advantage to be gained?—Why are spikes fixed into the outer rim of these sorts of wheels?—Explain how time is lost as power is gained? — What machines are to be referred to the principle of the wheel and axle?—Explain the principles of those crancs in which men walk in order to raise and lower weights? — How is the action of these crancs explained? — What guard is there to prevent danger in these cranes? — How is the wheel and axle to be referred to the principle of the lever? — See fig. 22 and 23.

CONVERSATION XVIII.

OF THE PULLEY.

Father. The third mechanical power is the *pulley*, which is a circular flat piece of wood or metal, termed the box or sheave, or the *block*, containing a wheel moveable about an axis, with a string running in a groove round it, by means of which a weight may be pulled up. It may be explained on the principle of the lever. The line, *ab*, may be conceived to be a lever, whose arms, *ac* and *bc*, are equal, and *c* the fulcrum, or centre of motion. If, now, two equal weights, *w* and *p*, be hung on the cord passing over the pulley, they will balance one another, and the fulcrum will sustain both.

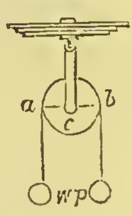


Fig. 24.

Ch. This pulley, then, like the common balance, gives no advantage.

Fa. From the single *fixed* pulley no mechanical advantage is derived; but, nevertheless, it is of great importance in changing the direction of a power; and is very much used in buildings for drawing up small weights, by drawing down the string: as it is far easier for a man to raise such burdens by means of a single pulley than to carry them up a long ladder. Pulleys are also used for drawing up curtains, sails of ships, &c.

Em. Why is it called a mechanical power?

Fa. Although a single fixed pulley gives no advantage, yet, when it is not fixed, or when two or more are combined into what is called a *system* or *tackle of pulleys*, they then possess all the properties of the other mechanical powers. Thus, in *cdp*, *c* is the fulcrum; therefore, a power, *p*, acting at *b*, will sustain a double weight, *w*, acting at *a;* for *bc* is double the distance of *ac* from the fulcrum.

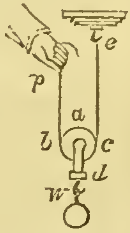


Fig. 25.

Again, it is evident, in the present case, that the whole weight is sustained by the cord *cp;* and whatever sustains half the cord sustains also half the weight; but one half is sustained by the fixed hook, *e;* consequently, the man or power at *p*, has only the other half to sustain, or, in other words, any given power at *p* will keep in equilibrium a double weight at *w*.

Ch. Is the velocity of *p* double that of *w?*

Fa. Undoubtedly. If you compare the space passed through by the hand at *p*, with that passed through by *w*, you will find that the former is just double of the latter; and, therefore, the *momenta* of the power and weight, as in the lever, are equal.

Ch. I think I see the reason of this: for, if the weight be raised an inch, or a foot, both sides of the cord must also be raised an inch, or a foot: but this cannot happen unless that part of the cord at *p* pass through two inches, or two feet, of space.

Fa. You will now easily infer, from what has been already shown of the single *moveable* pulley, that in a *system of pulleys*, the power gained must be estimated by doubling the number of pulleys in the lower or moveable block: so that,

when the fixed block, *a*, contains two pulleys which only turn on their axes, and the lower block, *b*, contains also two pulleys, which not only turn on their axes, but also *rise* with the weight, the advantage is as four: that is, a single pound at *p* will sustain four at *w*.

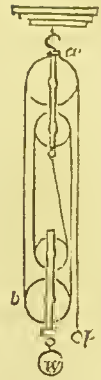


Fig. 26.

Ch. In the present instance also I perceive that, by raising *w* an inch, there are four ropes shortened each an inch; and therefore the hand must have passed through four inches of space in raising the weight a single inch; which establishes the maxim, that "what is gained in power is lost in space." But, Papa, you have only talked of the power of balancing or sustaining the weight. Something more must, I presume, be added to raise it.

Fa. Certainly. Considerable allowance must also be made for the friction of the cords, pivots, or axes, on which the pulleys turn. In the mechanical powers generally, one third of the power must be added for the loss sustained by friction, and for the imperfect manner in which machines are commonly constructed. Thus, if by *theory* you gain a power of 600, in *practice* you must reckon only upon 400. In the pulleys which we have been describing, writers have taken notice of three things, which take much from the general advantage and convenience of pulleys as a mechanical power. The *first* is, that the diameters of the axes bear a great proportion to their own diameters. The *second* is, that, in working, they are apt to rub against one another, or against the side of the block. And the *third* disadvantage is, the stiffness of the rope that goes over and under them.

The first two objections have been, in a great degree removed by the concentric pulley, invented by Mr. White: *b* is a solid block of brass, wherein grooves are cut, in the proportion of 1, 3, 5, 7, 9, &c.; and *a* is another block of the same kind, whose grooves are in the proportion of 2, 4, 6, 8, 10, &c.; and round these grooves a cord is passed; by which means they answer the purpose of so many distinct pulleys, every point of which, moving with the velocity of the cord in contact with it, the whole friction is removed to the two centres

Fig. 27.

of motion of the blocks *a* and *b:* besides, it is of no small advantage, that the pulleys being all of one piece, there is, in consequence, no rubbing one against the other.

Em. Do you calculate the power gained by this pulley by the same method as with the common pulley?

Fa. Yes; for pulleys of every kind the rule is general: the advantage gained is found by doubling the number of the pulleys in the lower block: in the pulley before you there are six grooves, which answer to as many distinct pulleys, and, consequently the power gained is twelve; or, one pound at *p*, will balance twelve pounds at *w*.

Various other systems of pulleys have been invented, but it would not be worth while to incumber your memory with them, as they have been found less practicable than those we have described.

Ch. When there is a combination of pulleys, what did you say it was denominated, Papa?

Fa. It is called a *Tackle;* and the box containing the pulleys is called a *Block.*

Ch. In a combination of separate pulleys, where each lower pulley has its own peculiar rope, or string, what must be the proportion of the power to the weight?

Fa. It must be as one is to two, continually doubled as many times as there are lower pulleys. You have learned that the upper pulley, over which the rope runs, only serves to alter the direction of the power. What, then, is the power it gains by the addition of the lower pulley?

Ch. By means of that, the power moves twice as fast as the weight; and, therefore, to make an *equilibrium*, the weight must be double the power.

QUESTIONS FOR EXAMINATION.

Can the principle of the pulley be referred to that of the lever? See fig. 24. — Is any mechanical advantage gained from the *single fixed pulley?* — Why is it called a mechanical power? — Explain its action by fig. 25. — In the lever what must be the proportion of the momentum of the power to that of the lever? — How is the power estimated in a system of pulleys? — How much is to be allowed for friction and other imperfections in the mechanical powers? — What are the chief defects in the operation of pulleys? — Have these or any of them been obviated; and by what means? — What is the general rule for calculating the power of pulleys?

CONVERSATION XIX.

OF THE INCLINED PLANE.

Father. We may now describe the *inclined plane*, which is the *fourth* mechanical power. It is merely a slope or declivity employed to facilitate the drawing up of great weights.

Ch. You will not be able, I think, to reduce this also to the principle of the lever.

Fa. No: it is a distinct principle; and some writers on these subjects reduce at once the six mechanical powers to two; viz., the *lever* and the *inclined plane.*

Em. How do you estimate the advantage gained by this mechanical power?

Fa. The method is very easy; for, just as much as the length of the plane exceeds its perpendicular height, so much is the advantage gained. Suppose *ab* a plane standing on the table, and *cd* another plane inclined to it; if the length, *cd*, be three times greater than the perpendicular height, the cylinder, *e*, will be supported upon the plane, *cd*, by a weight equal to the third part of its own weight.

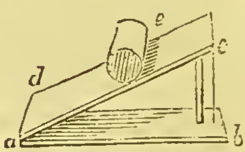


Fig. 28.

Em. Could I, then, draw up a weight on such a plane with a third part of the strength that I must exert in lifting it up at the end?

Fa. Certainly you might, making allowance, however, for the friction: but then, you must observe that, as in the other mechanical powers, you will have three times the space to pass over; or, as you gain power you will lose time.

Ch. Now I understand the reason why, sometimes, there are two or three strong planks laid from the street to the ground-floor warehouses, forming an inclined plane, on which large casks and heavy packages are raised or lowered.

Fa. The inclined plane is chiefly used for raising heavy weights to small heights; for, in warehouses situated in the upper parts of buildings, cranes and pulleys are better adapted for the purpose: it is now, however, beginning to be much employed in the construction of roads, especially rail-roads.

Ch. I have sometimes, Papa, amused myself by observing the difference of time which one marble has taken to roll down

a smooth board, and another which has fallen by its own gravity without any support.

Fa. And if it was a long plank, and you took care to let both marbles drop from the hand at the same instant, I dare say you found the difference very evident?

Ch. I did: and now you have enabled me to account for it very satisfactorily, by showing me that as much more time is spent in raising a body along an inclined plane than in lifting it up at the end, as that plane is longer than its perpendicular height. For I take it for granted that the rule holds good in the descent as well as in the ascent.

Fa. If you have any doubt remaining, a few words will clear it up. Suppose your marbles placed on a plane perfectly horizontal, as this table, they will remain at rest wherever they are placed; but if you elevate the plane in such a manner that its height be equal to half the length of the plane, it is evident, from what has been shown before, that the marbles will require a force equal to half their weight to sustain them in any particular position. Suppose, then, the plane perpendicular to the table; the marbles will descend with their whole weight; for now the plane contributes in no respect to support them; consequently, they would require a power equal to their whole weight to keep them from descending.

Ch. Is the swiftness, therefore, with which a body falls to be estimated by the force with which it is acted upon?

Fa. Certainly: for you are now sufficiently acquainted with philosophy to know that the effect must be estimated from the cause. Suppose an inclined plane thirty-two feet long, and its perpendicular height sixteen feet; what time will a marble take in falling down the plane, and also in descending from the top to the earth, by the force of gravity?

Ch. By the attraction of gravitation, a body falls sixteen feet in a second, (see p. 28,) therefore the marble will be one second in falling perpendicularly to the ground; and, as the plane is double its height, the marble must take two seconds to roll down it.

Fa. I will try you with another example. If there is a plane 64 feet in perpendicular height, and 3 times 64, or 192 feet long, tell me what time a marble will take in falling to the earth by the attraction of gravity, and how long it will be in descending down the plane.

Ch. By the attraction of gravity it will fall in two seconds; because, by multiplying the sixteen feet which it falls in the first second by the square of two seconds, or four, which is the time, I get sixty-four, the height of the plane. But the plane being three times as long as it is perpendicularly high, it must be three times as many seconds in rolling down the plane as it was in descending freely by the force of gravity; that is, six seconds.

I know, Papa, that the whole force with which a weight descends in a right line towards the centre of the earth, is called the *absolute* gravity of that weight. What is the diminished force called, with which the weight descends on an inclined plane?

Fa. It is called the *relative* gravity. If, therefore, a plane be perpendicular, the relative gravity upon it is equal to the absolute gravity; but, if a plane be horizontal, there is no relative gravity whatever.

Em. Pray, Papa, what common instruments are to be referred to this mechanical power, in the same way as scissars, pincers, &c., are referred to the lever?

Fa. Chisels, hatchets, and such other sharp instruments as are sloped down to an edge on one side only may be referred to the principle of the inclined plane.

QUESTIONS FOR EXAMINATION.

Do all writers on mechanical subjects reckon *six* mechanical powers? — How are we to estimate the advantage gained by the inclined plane? See fig. 28. — What power would be necessary to draw a given weight up such a plane as that described in the figure? — What is the reason that heavy packages are drawn up planks from the street to a warehouse instead of being lifted perpendicularly up? — Why does a marble take longer in descending an inclined plane, than it would in falling perpendicularly by the force of gravity? —Explain this more particularly by the instance of a marble on horizontal and inclined planes. — How is the swiftness of a falling body to be estimated? — If a plane is three times as long as it is high, what will be the proportion of the perpendicular fall of a marble, to its descent down the inclined plane? —What instruments are to be referred to this mechanical power?

CONVERSATION XX.

OF THE WEDGE.

Father. The next mechanical power is the *wedge*, which is made up of two inclined planes, as *def* and *cef*, joined together at their bases, *hefg*:—*dc* is the whole thickness of

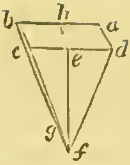


Fig. 29.

the wedge at its back, *abcd*, where the power is applied, and *df* and *cf* are the lengths of its sides: now there will be an equilibrium between the power impelling the wedge downward and the resistance of the wood or other substance acting against its sides, when the thickness, *dc*, of the wedge is to the length of the two sides, or, which is the same thing, when half the width or thickness, *de*, of the wedge, at its back, is to the length of *df*, one of its sides, as the power is to the resistance.

Ch. This is the principle of the inclined plane.

Fa. It is: and notwithstanding all the disputes which the methods of calculating the advantage gained by the wedge have occasioned, I see no reason to depart from the opinion of those who consider the wedge as a double inclined plane.

Em. I have seen people cleaving wood with wedges; but they seem to have no effect unless struck sharply, and with great force?

Fa. Certainly, my child; for the power of the attraction of cohesion, by which the parts of wood adhere together, is so great as to require a considerable *momentum* to separate them. Did you observe nothing else in the operation, worthy of your attention?

Ch. Yes: I also took notice that the wood generally split a little below the place which the wedge reached.

Fa. This happens in cleaving most kinds of wood; and then the advantage gained by this mechanical power must be in proportion as the length of the sides of the cleft in the wood is greater than the length of the whole back of the wedge. There are other peculiarities in the action of the wedge; but, at present, it is not necessary to refer to them.

Em. Since you said that all instruments which sloped off to an edge on one side only were to be explained by the principle of the inclined plane; so, I suppose, those which slope to an edge on both sides must be referred to the principle of the wedge?

Fa. They must: many chisels are so made, and almost all sorts of axes, nails, pins, needles, awls, &c., are also modifications of the wedge, also the teeth of animals. The angle of the wedge is also a matter of importance; the softer the substance to be divided, the more acute may the wedge be

constructed. In tools for cutting wood, the angle is generally about 30°; for cutting iron from 50° to 60°; and for brass from 80° to 90°.

Ch. Is the wedge much used as a mechanical power?

Fa. It is of considerable importance in a great variety of cases, where the other mechanical powers are of no avail: and this arises from the momentum of the blow, which is greater, beyond comparison, than the application of any dead weight or pressure, such as is employed in the other mechanical powers. Hence it is used in splitting wood, rocks, &c.; and even the largest ship, when in dock, may be raised to a small height by driving a wedge under the keel. It is also used for raising up the beam of a house, when the floor gives way, by reason of too great a burden being laid upon it, and for securing scaffolding, fixing door frames, and many other purposes in building. It is usual also in separating large mill-stones from the sand-rocks, to bore horizontal holes under them in a circle, and fill them with pegs or wedges made of dry wood, which, gradually swelling by the moisture of the earth, in a day or two lift up the mill-stone without breaking it.

It is on the principle of the wedge that saws are employed. A series of wedges are cut in the edge of a thin plate of steel, which, by its weight, tends perpetually to drive the points of these wedges into the substance on which it acts, and by its longitudinal motion it presents a fresh surface continually to their action. When the teeth are small, the force employed is proportionately small: thus saws with large teeth are used for soft substances, and those with small teeth for hard substances. Most cutting instruments, as scythes, sabres, table-knives, &c., act as saws, by the extremely fine roughness produced on their edges by grinding or other sharpening.

Ch. Is it on the same principle that stone, glass, and gems, &c., are cut?

Fa. Stones are usually sawn by a plain piece of metal without teeth; the small angular particles of the substance, or of some harder stone, act as little wedges, which are moved backward and forward by the action of the blade. In cutting granite, emery is used. For glass, emery mixed with water is dropped on a sharp edged wheel, which is put into rapid motion, and for engraving gems, diamond-powder is used,

which is made to drop on a slender piece of soft iron revolving with great velocity on its axis.

On the principle of the wedge are constructed files; their surfaces are studded with small wedges, which act in the same manner as the saw.

QUESTIONS FOR EXAMINATION.

Of what is the wedge formed?—Refer to figure 27 and explain the principle of this mechanical power.—Is the principle of the wedge similar to that of the inclined plane?—Why is great force necessary in the use of the wedge?—How is the power of the wedge estimated?—What instruments are to be referred to the wedge?—To what particular purposes is the wedge applied?—How are mill-stones separated from the rocks?

CONVERSATION XXI.

OF THE SCREW.

Father. Let us now examine the properties of the *sixth* and last mechanical power, the *screw;* which, however, cannot be called a simple mechanical power, as it is never used without the assistance of a lever or winch; by means of which it becomes a compound engine of great power in pressing bodies together, or in raising great weights. *ab* is the representation of one, with the lever *h*.

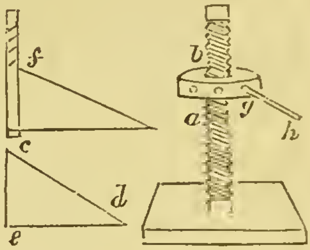


Fig. 29.

Em. You said just now, Papa, that all the mechanical powers were reducible either to the lever or to the inclined plane. How can the screw be referred to either?

Fa. The screw is composed of two parts; one of which, *ab*, is called the screw, and consists of a spiral protuberance, called the *thread*, which may be supposed to be coiled round a cylinder: the other part, *g*, called the *nut*, is perforated to the dimensions of the cylinder; and in the internal cavity is also a spiral groove adapted to receive the thread. To this nut is also attached the lever, without which the screw is never used as a mechanical power. Now, if you cut a slip of writing-paper in the form of an inclined plane, *cde*, (fig. 29) and then wrap it round a cylinder of wood, as a pencil, you will find that it makes a spire answering to the spiral part of

the screw. Moreover, if you consider the ascent of the screw, it will be evident that it is precisely the ascent of an inclined plane, but in a spiral direction instead of in a straight line.

Ch. By what means do you calculate the advantage gained by the screw?

Fa. At first sight it is evident that two things are to be taken into consideration: the first is, the distance betwcen the threads of the screw; the second, the length of the lever.

Ch. Now I comprehend pretty clearly that it is an inclined plane, and that its ascent is more or less easy as the spiral threads are nearer or farther distant from each other; so that what is saved in power is lost in time.

Fa. Well, then, I will now, by a question, ascertain whether your conceptions be accurate. Suppose two screws, the circumferences of whose cylinders are equal to one another; but in one, the distance of the threads to be an inch apart; and that of the threads of the other only one-third of an inch. What will be the difference of the advantage gained by one of the screws over the other?

Ch. The one whose threads are three times nearer than those of the other must, I should think, give an advantage three times greater.

Fa. Give me the reason for your assertion.

Ch. From the principle of the inclined plane, I learn that, if the *height* of two planes were the same, but the length of one twice, thrice, or four times greater than that of the other, the mechanical advantagc gained by thc longer planc would be two, three, or four times greater than that gained by the shorter. So, therefore, in the present case, thc height gained in both *screws* is the same, that is, one inch; but the space passed in that, of whose threads three go to an inch, must be three times as great as the space passed in the other: hence, as space is passed, or time lost, just in proportion to the advantage gained, I infer that three times more advantage is gained by the screw whose threads are one-third of an inch apart than by that whose threads are only an inch apart.

Fa. Your infcrence is just, and naturally follows from an accurate knowledge of the principle of the inclined plane. But we have said nothing about the lever.

Ch. This seemed hardly necessary; it being so obvious, to any one who will think a moment, that power is gained by

that, as in levers of the first kind, according to the length *gh* from the nut.

Fa. Let us now calculate the advantage gained by a screw, the threads of which are half an inch distant from one another, and the lever seven feet long.

Ch. I think you once told me that if the radius of a circle was given, in order to find the circumference, I must multiply that radius by 6.

Fa. I did; for although that is not quite enough for great accuracy, yet it will answer all common purposes, till you are a little more expert in the use of decimals.

Ch. Well, then, the circumference of the circle made by the revolution of the lever will be, 7 feet multiplied by 6, which is 42 feet, or 504 inches; but, during this revolution, the screw is raised only half an inch; therefore the space passed by the moving power will be 1008 times greater than that gone through by the weight; consequently the advantage gained is 1008; or, one pound applied to the lever will balance 1008 pounds acting against the screw.

Fa. You perceive that it follows, as a corollary from what you have been saying, that there are two methods by which you may increase the mechanical advantage of the screw.

Ch. Without doubt. It may be done either by taking a longer lever, or by diminishing the distance of the threads of the screw.

Fa. Tell me the result, then, supposing the threads of the screw to be so fine as to stand at the distance of but one quarter of an inch asunder, and the length of the lever to be 8 feet, instead of 7.

Ch. The circumference of the circle made by the lever will be 8 multiplied by 6, which is equal to 48 feet or 576 inches, or 2304 quarter inches; and as the elevation of the screw is but one quarter of an inch, the space passed by the power will therefore be 2304 times greater than that passed by the weight; which is the advantage gained in this instance.

Fa. A child, therefore, capable of moving the lever sufficiently to overcome the friction, with the addition of a power equal to one pound, will be able to raise 2304 pounds, or something more than 20 hundred weight and a half. The strength of a powerful man would be able to do 20 or 30 times as much more.

Ch. But I have seen in paper mills and other manufactories, six or eight men use all their strength in turning a screw, in order to press out the water from the newly made paper, or to reduce packages to a smaller compass. The power applied in those cases must have been very great indeed.

Fa. It was: but I presume you are aware that it cannot be estimated by multiplying the power of one man by the number of men employed.

Ch. That is, because the men standing at unequal distances at the lever, have not an equal power upon the screw; for although he who stands nearest to the screw may exert the same strength as the rest, yet it is by no means so effective as if he were placed at the extremity of the lever.

Fa. The true method, therefore, of calculating the power of this machine, aided by the strength of these men, would be to estimate accurately the power of each man according to his position, and then adding all these separate advantages together for the total power gained.

Em. A machine of this kind is, I believe, used for many purposes.

Fa. Yes, it is found in every book-binder's work-shop, and is particularly useful where persons are desirous of having small books reduced to a still smaller size for the pocket. It is also the principal machine used for coining money, for letter-press printing in the common way; for packing, stamping, and in cider and wine presses.

There is no wood so hard that a screw will not penetrate, and when once fixed, no power acting in the direction of its length can tear it out.

A magnificent apparatus for coining was invented some years since by Mr. Boulton; the whole machinery of which is worked by an improved steam-engine: it rolls the copper for half-pence, works the screw presses for cutting out the circular pieces of copper, and coins both the faces and edges of the money at the same time. By this machinery, four boys, ten or twelve years old, are capable of striking 30,000 guineas in an hour; and the machine itself keeps an unerring account of the pieces struck.

Em. I have also observed that the screw is used for pressing cheese, &c.

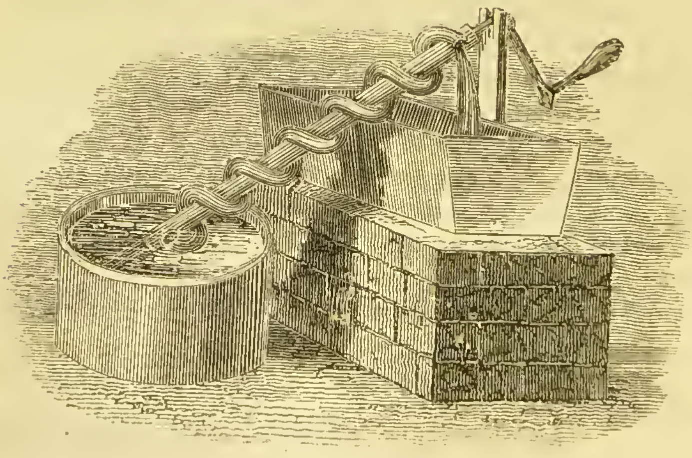
Fa. It would, my dear, be an almost endless task to

attempt enumerating all the purposes to which the screw is applied in the mechanical arts. Suffice it to say that, wherever great pressure is required, there the power of the screw is almost indispensable, for it acts continually with the same pressure in the same direction, and without releasing its hold.

Ch. Before we close this subject, Papa, will you tell me what the *Endless Screw* is? and what is meant by the *Archimedes Screw*, by which, we read, some steam vessels are propelled?

Fa. The endless screw is a screw combined with a wheel and axle, and in such a way that the thread or worm of the screw works into teeth or cogs fixed on the circumference of the wheel. If the power be applied to the handle of the screw, one revolution will move the wheel the distance of one of its cogs. If a weight be attached to the axle of the wheel, then there will be equilibrium when the power is to the weight, as the distance between the threads multiplied by the radius of the axle is to the length of the lever, or handle, multiplied by the radius of the wheel.

The *Archimedes Screw* is composed of a flexible tube round a cylinder in the form of a screw: and if this be placed obliquely in water or other fluid, and the screw be turned, the body will ascend, because the part of the screw behind it becomes more inclined than the part before it, and it is consequently urged forward and advances up the spiral, where it



empties into a vessel or reservoir put to receive it, as you may observe in the engraving; and it is on this principle that it is used as a propelling power.

The wedge and the screw you have now found to be not *simple*, but *compound* powers. How is the power of the wedge calculated?

Ch. The power and weight of the wedge, *in equilibrio*, will be to each other as the thickness of the back of the wedge is to the perpendicular length of the wedge, measured from the dividing edge at the back.

Fa. Are all compound machines estimated in like manner?

Ch. Yes; for we have only to compute what would be the proportion of the velocities of the weight and power, and take their forces in reciprocal proportion of those velocities. But, Papa, is there never any deviation, in machines generally, from the rules here laid down?

Fa. These rules are demonstrated to be true from the laws of motion; but if a machine differ from them (as all machines will do in some degree) the difference must be ascribed to friction and the resistance of the medium, or to some irregularity in the management of the machine, or some imperfection in the materials. Now friction is the resistance which bodies meet with in rubbing against each other; in fact, there is no such thing as perfect smoothness in nature.

Ch. Are not polished metals, Papa, perfectly smooth?

Fa. Polished metals, though they have that appearance, are very far from being perfectly smooth, as you can yourself discover by looking at them through a good magnifying glass: so that when two bodies come in contact, the minute projecting parts of the one fall into the hollows of the other and produce more or less friction; and if apparently ever so smooth, this friction is usually reckoned to destroy one-third of the power of a machine. Friction is considerably diminished by the application of oil or other grease to the rubbing surfaces, as you may observe in wheels, locks, hinges; for this application acts as a kind of polish in filling up the cavities of the rubbing surfaces.

Ch. What surfaces cause the most friction?

Fa. It has been found that less friction is occasioned by the contact of bodies of different substances than of the same; as of wood against metal, metal against stone, &c.

There are two kinds of friction; one very considerable arising from the *rubbing* or *sliding* together of two surfaces; and the other far less by the *rolling* of a circular body over another, which explains the great use of wheels in effecting locomotion.

Ch. Then, Papa, in descending a steep hill, we fasten one of the wheels by a shoe or drag, in order to decrease the velocity of the carriage, by increasing the friction.

Fa. Yes; the rolling friction of one of the wheels is changed into the dragging friction; and when castors are put to the legs of a table the dragging is changed into the rolling friction, to facilitate the moving of the table.

QUESTIONS FOR EXAMINATION.

What is the sixth mechanical power? — Is this a simple mechanical power? — Of what is the *screw* composed? — Show me by the figures the construction of the screw? — How is the advantage gained by the screw calculated? — Tell me why power is gained in the screw in proportion to the nearness of the threads. — What advantage is gained by a screw, the threads of which are a quarter of an inch apart, and the lever used, six feet long? — By what methods can you increase the mechanical advantage of the screw? — Is the power gained by this mechanical power very great? — When several men are employed in turning a screw, how is the power to be estimated? — Is the principle of the screw of general use? — Do you recollect what operations Mr. Boulton's coining-apparatus performs? — How many guineas can four boys coin in an hour?

CONVERSATION XXII.

OF THE PENDULUM.

Charles. My dear Papa, after we left you last night, we fancied we had been but a very little time engaged listening to your explanation of that interesting subject, the power of the screw, so that, on looking at the clock to observe the time, our attention was attracted to the *Pendulum*, which we do not remember you to have explained. Is it a mechanical power?

Fa. The *Pendulum*, though not a mechanical power, is of great importance in measuring time; and we may describe it as a heavy body, hanging by a line or rod, which is moveable about a centre; and the body thus suspended being put in

motion describes an arc, in one half of which it descends, and ascends in the other. *pc* is a pendulum, consisting of the ball, *p*, attached to the thread, *pc*, which is fastened to the point, *c*, and is moveable round it. If the ball, *p*, were let free it would fall in the vertical line, *pl*, but being retained it falls through the arc *pa*: and at *a* it has acquired a velocity that would carry it along *ad*, but being prevented from going along *ad* by the string which draws it to the centre, it describes the curve *ae*. Having arrived at *e*, it will fall back again to *a*, and go on with its acquired velocity to *p*, and so on continually backwards and forwards. Each swing that it makes is called a vibration, or oscillation. The vibrations of the same pendulum, whether small or great, are performed in nearly equal times.

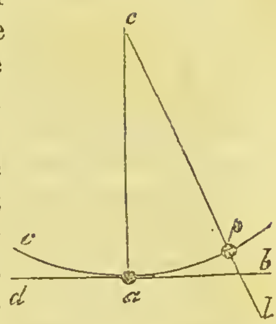


Fig. 31.

Ch. How long a time does the pendulum occupy in making these vibrations?

Fa. The longer the pendulum is, the slower are its vibrations, and the contrary. A pendulum to vibrate seconds in our latitude should be 39.13 inches long: if it was required to make one to vibrate $\frac{1}{2}$ seconds, it would be only the fourth part of the length of that which vibrates seconds; viz. $\frac{39.13}{4} = 9.78$: and one to vibrate only once in two seconds would be four times the length of that which vibrates seconds, namely $39.13 \times 4 = 157.52$ inches.

Pendulums of the same length vibrate slower the nearer they are brought to the equator, because gravity, on which the vibrations depend, is less at the equator than it is nearer the poles. A pendulum that is to vibrate seconds at the equator must be somewhat shorter than it is in this latitude, which, again, is longer than one would be at the poles.

Ch. If a pendulum were to hang perpendicularly it would, by the attraction of gravitation, remain at rest like a plumb-line, unless put in motion by some external force; would it not, Papa?

Fa. It would: but if you raise it up, gravity would bring it back to its perpendicular position, and instead of remaining there, the velocity it has acquired during its descent will impel it onward, so that from being confined at the centre it will rise on the opposite side to an equal height: here, again, gravity brings it back, and its velocity carrying it onwards as before, so it vibrates continually.

Ch. Then, I suppose, this is what may be called *Perpetual* motion?

Fa. No; it is not perpetual because of the resistance of the air in which it vibrates, and likewise of the friction at the end attached, or, we may say, at its centre. If you could remove these interruptions, we should perhaps have perpetual motion, for the vibrations perform equal distances in equal times, whence these vibrations have been called *isochronous*, "performed in equal terms;" from two Greek words *isos* (*ισος*) "equal," and *chronos* (*χρονος*) "time."

Ch. How was this peculiar property discovered, and by whom?

Fa. This property was discovered by the celebrated Galileo, the improver of the telescope, and the philosopher who found out the Satellites of Jupiter; he has, in fact, done more than any of his contemporaries in extending the bounds of science and making it available to the popular mind. In respect of the Pendulum, it seems he was one evening attending the church at Pisa, and after the large chandelier was lighted up, it was left swinging; his attention was directed to it; and observing carefully that the vibrations were performed in equal times, he made, afterwards, experiments on other vibrating bodies, and eventually established the truth of his observations, and introduced the pendulum as a means of regulating an instrument for the measurement of time. You, yourself, can ascertain the truth of this law by counting the oscillations of a vibrating body; and you will find that, whether the pendulum is vibrating in an arc of four or five degrees, or even a fraction of a degree, an even time is required to perform the vibration.

Ch. I suppose, Papa, this amount of time is completely dependent on the weight attached to the wire?

Fa. By no means; neither the weight of the ball, nor the

substance of which it is made, nor even the shape in which it is formed, except so far as regards the resistance of the air, has anything to do with it, and I will prove it to you. Take two balls of different sizes, and substances, but the wires must be of equal length, and let them vibrate together: you will find that the time occupied in the vibration of each is the same. Gravity in its action upon a pendulum causes it to oscillate and exert its influence upon each particle of the matter composing the ball; so that but one particle suspended at the end of a thread would oscillate with the same velocity as any number of particles combined together in one body. I will now add, in respect of the time, that the time of the oscillations is as the square root of the length of the pendulum.

Ch. If that is the case, I suppose, were I to take three pendulums, whose lengths are as one, four, and nine respectively, the time required for the oscillation of the second will be twice as long as that of the first, and the time of the oscillations of the third will be three times that of the first, because 1 2 3 are the square roots of 1 4 9, respectively.

Fa. You are perfectly correct; and since the oscillations of a pendulum vary with its length, a certain length is required that it may beat seconds, that is, vibrate 60 seconds in a minute.

Ch. Then, I suppose, if our clock gets too fast or too slow, it must be regulated by lengthening or shortening the pendulum; just as, to make a pendulum which beats seconds at the pole of the earth, an alteration must be made in its length to make it beat seconds at the equator.

Fa. You are quite correct; but still there is another thing which has a considerable effect on the oscillation of the pendulum, which we must not pass unnoticed; and that is the increase or decrease of temperature. You know that a bar of metal which will pass easily when cold through an opening fitted to receive it, will not do so when heated red hot, because of the expansive power of heat; for a similar reason, the pendulum which beats seconds in a cold climate, would cease to do so when removed into a hotter temperature, for its length would be increased. This is remedied by making the pendulum of such material as will not be appreciably affected by change of temperature; a wooden rod, if preserved from the

moisture of the air, has been found highly serviceable in this respect; but the most ingenious contrivance, for which we are indebted to Mr. John Harrison, is the gridiron pendulum, composed of bars of different metals, so arranged as to correct each other's expansion; thus, let G be the ball of a pendulum, and S the point of suspension. A B C D is a steel frame, to which is attached the rod S F; and *a b c d* is a frame of some other metal, and is attached to the rod C D, at the points *c d*. At T, the rod T G is suspended, passing freely through an aperture at H. Now, if the temperature be raised, the frame, A B C D, will dilate downwards, that is, C D will be carried further from the point S; and if the mass of the pendulum be thus brought downwards, it will no longer beat seconds. But the frame *a b c d* is also expanded, and the expansion is upwards; so that while C D is lowered, *a b* will be raised. Now, if we suppose *a b* to be raised as much as C D is lowered, the distance of *a b* from S will remain unchanged. But the increase of temperature which expands the other part of the instrument, expands the rod T G, and therefore the distance between G and T is preserved. Now looking at the instrument generally, we observe that SF, AC, TG, when expanded by a rise of temperature, would tend to increase the distance between S and G; that is, the point of suspension and the bob. To prevent this, we must make the frame *c a b d* of such a metal, that its expansion upwards may exactly neutralize the combined downward expansions, and thus the distance between S and G will be preserved.

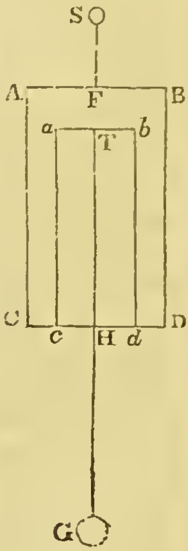


Fig. 32.

Ch. You said, Papa, that the length of a pendulum in the latitude of London to beat seconds should be little more than thirty-nine inches; would this do for Paris?

Fa. No: I will furnish you with an admirable table from Mr. Airy's treatise on the figure of the earth in the Encyclopedia Metropolitana, which gives the length in English inches of the pendulum to beat seconds in the most important latitudes.

Place.	*Latitude.*	*Length of Pendulum.*	*Observers.*
		INCHES.	
Spitzbergen............	79° - 50 N.	39·21469	Sabine.
Unst......	60 - 45	39·17162	Biot and Kater.
Leith Fort	55 - 59	39·15546	Ditto.
London.................	51 - 31	39·13929	Kater.
Paris....................	48 - 50	39·12851	Borda, Biot and Sabine.
Bordeaux..............	44 - 50	39·11296	Biot.
New York	40 - 43	39·10120	Sabine.
Sandwich Isles.........	20 - 52	39·04690	Freycinet.
Trinidad	10 - 39	39·01888	Sabine.
Bahia....................	12 - 59 S.	39·02433	Ditto.
Isle of France.........	20 - 10	39·04684	Freycinet and Duperry.
Cape of Good Hope...	35 55	39·07800	Ditto and Fallows.

We will now conclude this topic with a succinct account of the laws of pendulums:—1. The times of vibration of the same pendulum in small arcs are all equal. 2. The velocity of the ball or weight in the lowest point will be as the length of the chord of the arc which it describes in its descent. 3. The times of vibrations of different pendulums in small arcs, are proportional to the square roots of their respective lengths. 4. The lengths of pendulums are as the squares of the times of vibration. 5. In the latitude of London, a simple pendulum, that is, a fine thread with a small ball at the end, must be 39 inches and a fifth long to vibrate once in a second in a small arc.

QUESTIONS FOR EXAMINATION.

What is a pendulum? — What is the length of a pendulum to vibrate seconds in our latitude? — Do they vibrate in the same time at the equator? — What is the cause of the oscillation? — Does the pendulum observe a perpetual motion?—How and by whom was this peculiar property of the pendulum discovered? — Prove that it is not the weight of the ball that affects the time of the vibration? — How does gravity operate upon the pendulum?— How do the oscillations vary?—How is a clock regulated? — Does variation of temperature affect the pendulum?— How may this be remedied? — What is the gridiron pendulum? — By whom was it invented? — What are the five chief laws of pendulums?

SOME OF THE LEADING DEFINITIONS IN MECHANICS WHICH IT IS RECOMMENDED THAT THE PUPILS SHOULD COMMIT TO MEMORY

MATTER.

1. The properties of matter are impenetrability, divisibility, mobility, and inertia.

2. All bodies seem to possess the properties of attraction.

3. Impenetrability is the property by which two bodies cannot occupy the same part of space at the same time.

4. Divisibility is that property by which matter is capable of being divided.

5. Mobility is that property of matter by which it is capable of being moved.

6. Inertia is the tendency which matter has to continue in the state into which it is put whether of rest or motion.

7. SPACE is either absolute or relative.

8. Absolute space has no limits; and is itself immoveable.

9. Relative space is that part of absolute space which is occupied by any body.

10. MOTION is either absolute or relative.

11. Absolute motion is the motion that bodies have independently of each other, and only with regard to the parts of space.

12. Relative motion is the degree and direction of the motion of any body, when compared with that of another.

13. Accelerated motion is that in which the velocity of the motion continually increases.

14. Retarded motion is when the velocity continually decreases.

15. The velocity of uniform motion is estimated by the space moved over in a certain time.

16. The velocity of a body is ascertained by dividing the space by the time.

17. The space is estimated by the time multiplied into the velocity.

18. In accelerated motion, the space passed over is in proportion to the square of the time.

19. A body acted upon by one force moves in a straight line.

20. A body acted upon by one uniform force, and also by another accelerating force in a different direction, will describe a curve.

21. The momentum of a body is the force with which it moves, and is estimated by the quantity of matter multiplied into its velocity.

22. The attraction of cohesion acts at only very small distances.

23. The attraction of gravitation is that which masses of matter exert on each other at all distances.

24. Gravitation decreases from the surface of the earth as the squares of the distances.

25. The centrifugal force is the tendency which bodies that revolve round a centre have to fly off from it in a tangent to the curve they move in.

26. The centripetal force is that which prevents their flying off, by impelling them towards a centre; such is the attraction of gravitation.

27. The centre of gravity is that point in which the weight of a body is supposed to be collected.

28. A line drawn from the centre of gravity perpendicular to the horizon, is called the line of direction.

29. When the line of direction falls within the base of any body, that body will stand; but when it falls without the base, the body will fall.

30. There are three kinds of levers: the *first* is when the fulcrum is between

the power and the weight: the *second* is when the fulcrum is at one end of the lever, the power at the other, and the weight between them: the *third* is when the fulcrum is at one end, the weight at the other, and the power between them.

31. In all kinds of levers, the power is to the weight, as the distance of the weight from the fulcrum is to that of the power from the fulcrum.

32. A hammer is a bent lever, and differs only in form from a lever of the first kind.

33. A balance is a lever of the first kind with equal arms.

34. The steel-yard is likewise a lever of the first kind with a moveable weight.

35. In the wheel and axle, to obtain an equilibrium, the power must be to the weight, as the circumference of the wheel is to the circumference of the axle, or as the diameter of the wheel is to the diameter of the axle.

36. Pulleys are of two kinds, fixed and moveable.

37. In the fixed pulley, when the power and the weight are equal, there is no mechanical advantage obtained.

38. In the moveable pulley, there will be an equilibrium if the power is equal to half the weight only.

39. In the inclined plane there will be an equilibrium when the power is to the weight as the height of the plane is to the length.

40. In the wedge, the power will be to the weight as half the thickness of the wedge on the back is to the length of one of the sides.

41. The screw is always used with a lever; and the power is to the weight as the distance from one thread or spiral to another, is to the circumference of the circle described by the power.

ASTRONOMY.

FIRST CONVERSATION.

OF THE FIXED STARS.

FATHER — CHARLES — JAMES.

Charles. The delay occasioned by our unusually long walk has afforded us one of the most brilliant views of the heavens I ever witnessed. What a delightful study must Astronomy be! What does Astronomy mean, Papa?

Fa. The word *Astronomy* implies that science which explains the motions of the heavenly bodies, and the laws by which they are governed: it is derived from two Greek words *aster* (αστηρ) "a star," and *nomos* (νομο) "a law:" and it is my design to explain this wonderful study to you in our ensuing conversations, and I trust it will lead you to admire the wisdom and omnipotence of the Almighty, and to be ever ready to acknowledge His power and goodness in all that you survey.

Ja. Oh! thank you, Papa, I shall be delighted with the study, I am sure. How uncommonly clear it is to-night, and the longer I keep my eyes fixed on the stars, the more there seem to me to appear. Is it possible to count these stars, Papa? I have heard that they are numbered, and even arranged in catalogues according to their apparent magnitudes. Pray explain to us how this was done.

Fa. I will with great pleasure by and by; but at present, I must tell you that in viewing the heavens with the naked eye, we are very much deceived as to the supposed number of stars that are at any time visible. It is generally admitted, and on good authority, that, without the aid of glasses, there

are never more than a few thousand stars visible at any one time and place.

Ja. What, Papa! can I see no more than a few thousand stars, if I look all round the heavens? I should have thought there had been millions.

Fa. The number I have mentioned is, according to Dr. Herschel, the limit of what you can at one time behold: and that which leads you and others to conjecture that the number is so much larger, is owing to an optical deception.

Ja. What is meant by the term optical?

Fa. The term optical is an adjective, derived from the Greek word *opsis* (ὄψις) "sight," or *optomai* (ὄπτομαι) "I see;" hence we have the term Optics, the science of vision.

Ja. Are we liable to be frequently deceived by our senses?

Fa. We are, if we depend on them *singly;* but where we have an opportunity of calling in the assistance of one sense to the aid of another, we are seldom subject to this inconvenience.

Ch. Do you not know that if you place a small marble in the palm of the left hand, and then cross the second finger of the right hand over the first, and in that position, with your eyes shut, move the marble with the tips of the two fingers thus crossed, the one marble will appear to the touch as two? In this instance, without the assistancc of our eyes, we should be deceived by the sense of feeling.

Fa. Exactly so, and this shows that the judgment formed by means of a single sense is not always to be depended upon: yet this has nothing to do with the false judgment which we are said to form in respect of the number of the stars; but it may be useful in affording us a lesson of modesty, and instructing us that we ought not to close our minds against any fresh evidence offered on any subject, although that evidence may seem contradictory to the opinions we may have already formed. But to proceed with our subject; you say that you see millions of stars, although the ablest astronomers assert that, with the naked eye, you can at one time see but a few thousands.

Ch. I also, Papa, should have thought as my brother does, had you not asserted the contrary; and I am anxious to know how the deception happens; for I am sure there must be great deception somewhere if I do not at this time behold very many thousands of stars in the heavens.

Fa. You know that we see objects only by means of the rays of light which proceed from them in every direction. And you must, for the present, be satisfied when I tell you that the distance of the fixed stars from us is immensely great: consequently, the rays of light have to travel this distance, in the course of which, especially in their passage through our atmosphere, they are subject to numberless *reflections* and *refractions.* By means of these, various rays of light come to the eye; every one of which, perhaps, impresses upon the mind the idea of so many separate stars. Hence arises that optical fallacy by which we are led to believe that the stars which we behold are innumerable.

Ja. What is the meaning of the terms *reflected* and *refracted?*

Fa. The word *reflected* is derived from the Latin *reflecto,* "I bend back;" hence to bend the mind back upon itself: *reflection* of the rays of light, is a motion of the rays, by which, after striking on a body, such as a mirror, they are driven back. *Refracted* is derived from the Latin word *refringo, refractum,* "to break." Refraction of the rays of light is a deviation of the rays from the direct course, upon falling obliquely out of one medium into another of a different density. The term refraction applies to the distortion which is occasioned in the appearance of an object, viewed in parts only, by *refracted light;* thus an oar partially immersed in water appears bent, on account of the *refraction of light.*

Ja. Can you confirm your explanation of our deception by experiment?

Fa. You shall be gratified. In every case you ought to require the best evidence that the subject will admit of—

> To ask or search I blame thee not: for heaven
> Is as the book of God before thee set,
> Wherein to read his wondrous works, and learn
> His seasons, hours, or days, or months, or years.—MILTON.

I will show you two experiments which will greatly help to remove the difficulty.

Here are two common looking glasses, which, philosophically speaking, are *plane mirrors.* I place them in such a manner on the table, that they support one another from falling by meeting at the top. I now place this half-crown between them, on a book, to raise it a little above the table. Tell me

how many pieces of money you would suppose there were, if you did not know that I had used but one.

Ja. There are several in the glasses.

Fa. I will now alter the position of the glasses a little, by making them almost parallel to each other. Now look into them, and tell me what you see.

Ja. There are more half-crowns now than there were before.

Fa. It is evident, then, that by *reflection* only, a single object (for I have made use of but one half-crown) will appear to you to be very many.

Ch. If a little contrivance had been used to conceal the method of making the experiment, I should not have believed but that there had been several half-crowns instead of one.

Fa. Bring me your multiplying glass. Look through it at the candle. How many do you see? or, rather, how many candles should you suppose there were, did you not know that there was but one on the table?

Ja. A great many: and a pretty sight it is.

Ch. Let me see! yes, there are very many, but I can easily count them. There are sixteen.

Fa. There will be just as many images of the candle, or any other object at which you look, as there are different surfaces on your glass. For, by the principle of *refraction*, the image of the candle is seen in as many different places as the glass has surfaces: consequently, if, instead of 16 there had been 60, or, if they could have been cut and polished so small, as to be 600, then the single candle would have given you the appearance of 60 or 600. What think you now about the stars?

Ja. Since I have seen that *reflection* and *refraction* will each, individually, afford such optical deceptions, I can no longer doubt but that, if both these causes are combined as you say they are with respect to the rays of light coming from the fixed stars, a thousand real luminaries may have the power of exciting in my mind the idea of millions.

Fa. I will mention another experiment, for which you may be prepared against the next starlight night. Get a long narrow tube, the longer and narrower the better, provided its weight does not render it unmanageable; and through it examine any one of the largest fixed stars, which are called stars of the *first* magnitude; and you will find that, though the tube takes in as much sky as would contain many such stars,

yet that the single one at which you are looking is scarcely visible, by the few rays which come *directly* from it. This is another proof that the brilliancy of the heavens is much more owing to *reflected* and *refracted* light than to the direct rays proceeding from the stars.

QUESTIONS FOR EXAMINATION.

What is the meaning of the term astronomy?—How many stars are there supposed to be visible at one time, and at one place?—As the number appears to be much greater than 1000, what is the cause of the deception?—How do you illustrate this?—By what experiment?—And what is meant by the term optical?—How are objects seen?—And to what are the rays of light subject in their passage from the fixed stars to the earth?—By what means can a single object be made to appear like many?—In looking through a multiplying glass at a single object, how many images of that object will be seen?—What other experiment is there to prove that the brilliancy of the heavens is chiefly owing to *reflected* and *refracted* light?—What is the meaning of the word *reflected?*—What, of *refracted?* and whence are these terms derived?

CONVERSATION II.

OF THE FIXED STARS—*continued.*

Charles. Another beautiful evening presents itself. Shall we take the advantage which it offers us of going on with our astronomical lecture?

Fa. Willingly: for we do not always enjoy such opportunities as the brightness of the present evening affords.

Ja. I wish very much to know how to distinguish the stars, and to be able to call them by their proper names.

Fa. This you may very soon learn to do. A few evenings, well employed in this pursuit, will enable you to distinguish all the stars of the first magnitude which are visible, as well as the relative positions of the different constellations.

Ch. What do you mean by stars of the first magnitude?

Fa. The stars have been divided by astronomers into various classes, according to their brilliancy, which are called *Magnitudes.* The brightest stars are said to be of the first magnitude; the next decisive difference gives name to stars of the second magnitude; and so on, down to the sixth or seventh, which comprises the smallest stars visible to the naked eye. Telescopes, however, continue the series down to the

sixteenth magnitude; and by and by, perhaps, we may have instruments of superior power that will bring stars beyond the sixteenth magnitude within the range of our observation.

Ja. What are constellations, Papa?

Fa. The ancients, in order that they might the better distinguish and describe the stars, with regard to their situation in the heavens, divided them into constellations; that is, groups of stars; each group consisting of such stars as were near to each other; giving them names, derived from their mythology, of such men, animals, or things, as they fancied the space that they occupied in the heavens represented. The word *constellation* is derived from the Latin *con*, "together," and *stella*, "a star."

Ch. Is it, then, perfectly arbitrary, that one collection is called the *Great Bear*, another *the Dragon*, a third, *Hercules*, and so on?

Fa. It is: and though there have been additions to the number of stars in each constellation, and various new constellations discovered by modern astronomers, yet the original division of the stars into these collections was one of those few arbitrary inventions which has descended without alteration, otherwise than by addition, from the days of Hipparchus and Ptolemy down to the present time.

Before we proceed further I must now ask you, if you know how to find the four points of the compass, or, as they are usually called, the four cardinal points—viz., the North, South, West, and East?

Ja. Yes; I know, that if I look at the sun at noon, I am looking to the South; which is his position at that time. My back is then towards the North; the West is on my right hand, and the East on my left.

Fa. But you must learn to find these points without the assistance of the sun, if you wish to be an astronomer.

Ch. I have often heard of the *North Polar Star*. That will, perhaps, answer the purpose of the sun, when he has left us.

Fa. Certainly. Do you see those seven stars which are in the constellation of the *Great Bear?* Some people have supposed their position represents a *plough;* others say, that they are more like a *Wagon and Horses;* the four stars representing the body of the wagon, and the other three the horses; and hence they are called by some the Plough, and

by others, Charles's wain or wagon. Here is a drawing of it (fig. 1); *a b d g* represent the four stars forming the outline of the wagon, and *e z* B the three designating the horses.

Ch. What is the star P beyond this constellation?

Fa. That represents the polar star, to which you just now alluded; and you observe, that if a line were drawn through the stars *b* and *a*, and produced far enough, it would nearly touch it.

Ja. Let me see if I can point it out to you, Papa, in the heavens. There it is, I think. It shines with a steady and rather dead kind of light; but it appears to me to be a little to the right of the line passing through the stars *a* and *b*.

Fa. It would: and these stars are generally known by the name of the *pointers*, because they point to the North Pole, *p*, which is situated a little more than two degrees from the Polar star P.

Ch. Is that star always in the same part of the heavens?

Fa. It may be considered as uniformly maintaining its position, while the other stars seem to move round it as a centre. We shall have occasion to refer to this star again. At present, I have only directed your attention to it, as the proper method of finding the points of the compass or cardinal points by starlight.

Ja. Yes: I understand now, that if, by standing with my face to that star, I look to the North, the South is then at my back; on my right is the East, and on my left the West.

Fa. This is one important step in our astronomical studies: but we shall find that we can also make use of these stars as a kind of standard, in order to discover the names and positions of others in the heavens.

Ch. In what way must we proceed?

Fa. I will give you an example or two. Imagine a line drawn from the star *z*, leaving B a little to the left, and it will pass through that very brilliant star near the horizon towards the west.

Ja. I see the star. But how am I to know its name?

Fa. Look on the celestial globe for the star *z*, and suppose the line drawn on the globe as we imagined it done in the heavens, and you will find the star and its name.

Ch. Here it is. Its name is Arcturus.

Fa. Look at your diagram, and place Arcturus at A, which is

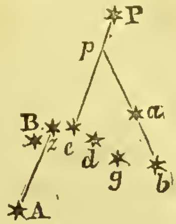


Fig. 1.

its relative position, in respect to the constellation of the Great Bear. Now, if you imagine a line drawn through the stars *g* and *b*, and extended a considerable way to the right, it will pass just above another very brilliant star. Examine the globe as before, and find its name.

Ch. It is *Capella*, the *Goat*.

Fa. Now, whenever you see any of these stars, you will know where to look for the others, without hesitation.

Ja. But do they never move from their places?

Fa. With respect to the whole heavens, they seem to move round the polar star; but they always remain in the same apparent relative position with respect to each other. Hence they are called *fixed* stars, in opposition to the *planets*, which, like our earth, are continually changing their places, both with regard to the fixed stars and to themselves also: but I must add that the term *fixed* is to be understood in a *comparative*, not absolute sense; for many of the stars are in a certain state of motion, though too slow to be perceptible without the most delicate and continued observations.

Ch. I think I now understand pretty well the method of acquiring a knowledge of the names and places of the stars.

Fa. With this, then, we will close our present conversation.

QUESTIONS FOR EXAMINATION.

What method did the ancient astronomers resort to in order that they might the better distinguish the stars?—By whom were the stars divided into constellations?—And for what purpose was this done? — How do you find the four cardinal points, East, West, North, and South, either by day or by night? — What are the two stars called, through which, if a line were drawn and extended far enough, it would nearly touch the *Polar star?* — Is the Polar star always in the same part of the heavens? — To what other purpose, besides that of finding the cardinal points, is the Polar star, and those near it, useful? — How would you by yourself be able to find out the name of any particular star in the heavens? — Do the fixed stars always keep their relative places in the heavens? — What is the difference between the fixed stars and the planets?

Obs. Although the fixed stars keep their relative places with respect to each other, yet they change their situations much with respect to us; some rising, others setting; some going over head, others just appearing in the horizon, and then disappearing. Some stars neither rise nor set, but seem to turn round one immovable point, near which is placed the *Polar* star above mentioned. The division of the stars into groups or constellations is quite arbitrary; but the system has ever been acknowledged, and used even by modern astronomers. The first person who numbered the stars, and reduced them to order, was Hipparchus, a native of Rhodes, about 120 years B.C.

CONVERSATION III.

OF THE FIXED STARS, AND THE ECLIPTIC.

Father. I have no doubt that you will have very little difficulty in discovering the north polar star as soon as we go into the open air.

Ja. I shall at once know where to look for that and the other stars which you pointed out last night, if they have not changed their places.

Fa. They always keep the same position, with respect to each other, though their situation, with regard to the heavens, will be different at different seasons of the year, and in different hours of the night. Let us go out and see.

Ch. The stars are all in the same places as we left them last evening. Now, Papa, if we imagine a straight line to be drawn through the two stars in the plough, which in the figure (1) are marked *d* and *g*, and to extend a long way down, it will pass, or nearly pass, through a very bright star, though not so bright as *Arcturus* or *Capella.* What is that star?

Fa. It is a star of the second magnitude: and if you refer to the celestial globe, in the same way as you were instructed last night, you will find it is called *Regulus*, or *Cor Leonis*, the *Lion's Heart.* By this method you will quickly discover the names of all the principal stars; and afterwards, with a little patience, you will easily distinguish the others, which are less conspicuous.

Ch. But I perceive these have not all names. How, then, are they specified?

Fa. If you look on the globe, you will observe that they are distinguished by the different letters of the Greek alphabet; and in those constellations where there are stars of different apparent magnitudes, the largest α (*a*), *alpha;* the next in size β (*b*), *beta;* the third, γ (*g*), *gamma;* the fourth, δ (*d*), *delta,* and so on.

Ja. Is there any particular reason for this?

Fa. The adoption of the characters of the Greek alphabet, rather than any other, was perfectly arbitrary. It is, however, of great importance that the same characters be used by astronomers in general of all countries; for by this means the science assumes a sort of universal language, and becomes in-

telligible throughout the world. Charles, you must teach your brother the Greek alphabet, he will have to acquire it when he is a little older, so that he may as well learn it now.

Ch. I shall be most happy to do so, Papa, and will you explain to us how this introduction of Greek letters applies?*

Fa. Let us suppose that if an astronomer in North America, Asia, or any other part of the earth, observe a comet or any particular appearance in that part of the heavens where the constellation of the *Plough* is situated, and he wish to describe it to his friend in Great Britain, that he may know whether it was seen by the inhabitants of this island; he has only to mention the time when he discovered it; its position in regard to some one of the stars, calling it by the Greek letter by which it is designated, and the course which it took from one star towards another. Thus he might say, that at such a time he saw a comet near δ in the Great Bear, and that its course was direct from δ to β, or any other letter, as it might happen.

Ch. Then, if his friend here had seen a comet at the same time, he would, by the same means, know whether it was the same or a different comet.

Fa. Certainly: and hence you perceive of what importance it is, that astronomers, in different countries, should agree to mark the same stars and groups of stars by the same characters. But to return to that star, to which you just called my attention, the *Cor Leonis*, it is not only a re-

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* THE GREEK ALPHABET.

Large.	*Small.*	*Names.*	*English Pronunciation.*	*Large.*	*Small.*	*Names.*	*English Pronunciation.*
Α	α	Alpha	a	Ν	ν	Nu	n
Β	β	Beta	b	Ξ	ξ	Xi	x
Γ	γ	Gamma	g	Ο	ο	Omīcron	ŏ
Δ	δ	Delta	d	Π	π	Pi	p
Ε	ε	Epsīlon	ĕ	Ρ	ρ	Rho	rh
Ζ	ζ	Zeta	z	Σ	σ ς	Sigma	s
Η	η	Eta	ē	Τ	τ	Tau	t
Θ	θ	Theta	th	Υ	υ	Upsīlon	u
Ι	ι	Iota	i	Φ	φ	Phi	ph
Κ	κ	Kappa	k	Χ	χ	Chi	ch
Λ	λ	Lambda	l	Ψ	ψ	Psi	ps
Μ	μ	Mu	m	Ω	ω	Omĕga	ō

markable star, but its position is also remarkable: it is situated in the *ecliptic.*

Ja. What is the ecliptic, Papa?

Fa. The *ecliptic* is an imaginary great circle in the heavens, which the sun *appears* to describe in the course of a year. If you look on the celestial globe, you will see it marked with a *red* line; an emblem, perhaps, of the fierce heat communicated to us by that body.

Ch. Why was it called the *Ecliptic?*

Fa. Because, when any heavenly bodies are in or near this circle, they are liable to be eclipsed, that is, deprived of the sun's light by some intervening body. It is derived from the Greek word *ecleipsis* (ἐκλειψις,) "absence, or deficiency."

Ja. But the sun seems to have a circular motion in the heavens every day.

Fa. It does: but this is called its apparent *diurnal* or daily motion, which is very different from the path it appears to traverse in the course of a year. The *former* is observed by the most inattentive spectator, who cannot but know that the sun is seen every morning in the East, at noon in the South, and in the evening in the West: but the knowledge of the *latter* must be the result of patient observation.

Ch. And what is the *green* line on the globe which crosses it?

Fa. It is called the *Equator,* which is an imaginary circle belonging to the earth, which you must still suppose, for the present, is of a globular form. If you can imagine the plane of the terrestrial equator to be produced to the sphere of the fixed stars, it would mark out a circle in the heavens, called the *celestial equator* or *equinoctial,* which would cut the *ecliptic* in two points. The word *equinoctial* comes from the Latin *æquus,* "equal," and *nox, noctis,* "night."

Ja. Can we trace the circle of the *ecliptic* in the heavens?

Fa. It may be done with tolerable accuracy in two ways. *First,* by observing several remarkable fixed stars, to which the moon in its course seems to approach. The *second* method is, by observing the places of the planets.

Ch. Is the moon, then, always in the ecliptic?

Fa. Not exactly so; but it is always either in the ecliptic, or within five degrees and a third of it, on one side or the other. The planets also, I mean, Mercury, Venus, Mars,

Jupiter, Saturn, and Herschel, are never more than eight degrees distant from the ecliptic.

Ja. How can we trace this line by help of the fixed stars?

Fa. By comparing the stars in the heavens with their representatives on the artificial globe; a practice which may be readily acquired. I will mention to you the names of those stars; and you may first find them on the globe, and then refer to as many of them as are now visible in the heavens. The first is in the *Ram's* horn, called *α Arietis*, about ten degrees to the *north* of the ecliptic; the second is the star *Aldebaran*, in the Bull's eye, six degrees *south* of the ecliptic.

Ch. Then, if at any time I see these two stars, I know that the ecliptic runs between them, and nearer to Aldebaran than to the star in the Ram's horn.

Fa. Yes: now carry your eye eastward to a distance somewhat greater from Aldebaran than that is east of α Arietis, and you will perceive two bright stars, at a small distance from one another, called *Castor* and *Pollux.* The lower one, and that which is the less brilliant, is Pollux, seven degrees on the north side of the ecliptic. Following the same track, you will come to *Regulus*, or the *Cor Leonis*, which, as I have already observed, is in the line of the ecliptic. Beyond this, and only two degrees south of that line, you will find the beautiful star in the Virgin's hand, called *Spica Virginis.* You then arrive at *Antares*, or the *Scorpion's Heart*, five degrees on the same side of the ecliptic. Afterwards, you will find *α Aquilæ*, which is situated nearly thirty degrees north of the ecliptic; and farther on is the star *Fomahaut*, in the fish's mouth, about as many degrees south of that line. The ninth and last of these stars is *Pegasus*, in the wing of the flying horse, which is nearly twenty degrees north of the ecliptic.

Ja. Upon what account are these nine stars particularly noticed?

Fa. They are selected as the most conspicuous stars near the moon's orbit, and are considered as excellent points from which the moon's distance may be calculated for every three hours of time; and hence are constructed those tables in the *Nautical Almanac*, by which navigators, in their most distant voyages, are enabled to estimate, on the vast ocean, the particular part of the globe on which they are.

Ch. What do you mean by the Nautical Almanac?

Fa. It is a kind of National Almanac, published by order of the Board of Admiralty, and intended chiefly for the use of sailors and others traversing the ocean. It was begun in the year 1767, by Dr. Maskelyne, the Astronomer Royal; and is published by anticipation for several years beforehand, for the convenience of ships going out upon long voyages. This work has been found eminently important in the late voyages of discovery made round the world, and for navigation generally, inasmuch as it contains a copious list of astronomical phenomena at sea, and the means of finding the longitude and other important matters.

QUESTIONS FOR EXAMINATION.

Do the fixed stars keep a constant situation with regard to the heavens? — How are those stars distinguished to which there are no particular names? — Is there any good reason why particular characters should be used for the same stars by all nations? — What do you mean by the ecliptic? — What is the equator? — What is the celestial equator or equinoctial? — How would you trace the ecliptic in the heavens? — Is the moon always in the ecliptic? — How far distant from the ecliptic can the planets wander? — What method would you adopt in tracing out to a friend the ecliptic? — Through what two remarkable stars does the ecliptic pass? — How is Regulus situated? — From what particular stars is the moon's distance calculated? (Here refer to the globe.) — For what purpose are these calculations made? — What is the Nautical Almanac, and to what purpose is it applied?

CONVERSATION IV.

OF THE EPHEMERIS.

Charles. Your second method, Papa, of tracing the ecliptic was by means of the position of the planets. Will you explain that now to us?

Fa. I will: and to render you perfectly qualified for observing the stars, I will devote the present conversation to the purpose of explaining the use of White's Ephemeris; a book published annually, and which is a necessary companion to every young astronomer.

Ja. What is the meaning of the word Ephemeris, Papa; and must we study the whole of this work to gain a knowledge of the stars?

Fa. The Ephemeris comprises many tables to show the places of a celestial body for *every day* at noon, and is a Greek

word (εφημερις) derived from *epi* (επι) "upon," and *hemera*, (ἡμερα) "a day:" the plural is *ephemerides*. And you must indeed either study that, or some other book of the same kind, if you would proceed in the best and most rational plan. Besides, when you know the use of this book, which you will, completely, with half an hour's attention, you have nothing more to do, to find the position of the planets at any day of the year, than to turn to that day in the Ephemeris, and you will instantly be directed to those parts of the heavens in which the different planets are situated. Turn to the second page.

Ch. Here the astronomical characters, I see, are explained.

Fa. The first twelve are the representatives of the signs into which the circle of the ecliptic is divided, called also the twelve signs of the *Zodiac*.

♈ Aries.	♌ Leo.	♐ Sagittarius.
♉ Taurus.	♍ Virgo.	♑ Capricorn.
♊ Gemini.	♎ Libra.	♒ Aquarius.
♋ Cancer.	♏ Scorpio.	♓ Pisces.

Every circle is supposed to be divided into 360 parts, called degrees; and since that of the ecliptic is also divided into 12 signs, each sign must contain 30 degrees. Astronomers subdivide each degree into 60 minutes, and each minute into 60 seconds, which are abbreviated thus, $^{\circ}$ — $'$ — $''$; so that to express an angle of 25 degrees, 11 minutes, and 45 seconds, we should write $25^{\circ} — 11' — 45''$. To express the situation of the sun for the first of January, 1822, which, by looking into the Ephemeris, is found to be in Capricorn, we should write ♑ $10^{\circ}\ 35'\ 48''$.

Ja. What do you mean by the Zodiac?

Fa. It is a broad circle, or belt, surrounding the heavens, about sixteen degrees wide, along the middle of which runs the ecliptic. The term Zodiac is derived from the Greek word *Zodion* (Ζωδιον) "a small animal," because each of the twelve signs was formerly designated by some animal: that which we now call Libra being, by the ancients, reckoned a part of Scorpio, the *Scorpion*.

Ja. Why are the signs of the Zodiac called by the several names of Aries, Taurus, Leo, &c.? I see no likeness in the

heavens to Rams, or Bulls, or Lions, which are the English meanings of those Latin words.

Fa. Nor do I. Nevertheless, the ancients saw, by the help of a strong imagination, a similarity in the outlines of those animals and the boundaries which certain groups of stars assumed in the heavens, and gave them these names, which have continued to this day.

Ch. Perhaps these were originally invented, in the same way as we sometimes figure to our imagination the appearances of men, beasts, ships, trees, &c., in the flying clouds, or in the fire.

Fa. They might possibly have no better authority for their origin, but some authors affirm that these constellations were invented in Egypt at some very remote period, and that they had a reference to the divisions of the seasons, and the agriculture of that country at the time of their invention. Sir William Jones ascribes the invention to Anaximander, about 560 B.C.; and remarks, also, that it had been known to the Hindoos from time immemorial. However, be that as it may, it will be useful for you to retain the names of the twelve signs in your memory, as well as the order in which they stand. I will therefore repeat some lines written by Dr. Watts, by means of which their English names and order may easily be remembered.

The *Ram*, the *Bull*, the heavenly *Twins*,
And, next the *Crab*, the *Lion* shines,
The *Virgin* and the *Scales;*
The *Scorpion*, *Archer*, and Sea-*Goat*,
The *Man* that holds the *watering* pot,
And *Fish* with glittering tails.

Ch. We come now to the characteristic marks placed before the planets.

Fa. These characters, like the former, are but a kind of short-hand, and, when remembered, are more readily written than the names themselves of the planets. They are as follow:

♅ Herschel, or Urănus.	⊕ The Earth.	⚳ Ceres.
♄ Saturn.	☉ The Sun.	⚴ Pallas.
♃ Jupiter.	♀ Venus.	⚵ Juno.
♂ Mars.	☿ Mercury.	⚶ Vesta.
	☽ The Moon.	

With the other characters you have no need to trouble yourselves till you come to calculate eclipses and construct astronomical tables; a labour which you may defer for some years to come. Now turn to the eighth page of the Ephemeris.

Ja. Have we no concern with the pages of the Ephemeris between the second and eighth ?

Fa. They do not contain anything that requires explanation. In the eighth page, after the common almanac for January, the two first columns point out the exact time of the sun's rising and setting at London: thus, on the 10th day of January he rises at fifty-eight minutes after seven in the morning, and sets at two minutes past four in the afternoon. The third column gives the *declination* of the sun.

Ja. What is meant by *declination*, Papa?

Fa. The *declination* of the sun, or of any heavenly body, is its distance from the imaginary circle in the heavens called the *equinoctial.* Thus you observe that the sun's declination on the 1st of January is 23° 3′ South; or, it is so many degrees South of the imaginary *equator.* Turn to March, 1822, and you will see that between the 20th and 21st days it is in the equator; for, at noon on the 20th it is only 16′ South, and at the same hour on the 21st it is 8′ North of that line: and when it is in the equator, it has then no declination.

Ch. Do astronomers always reckon from 12 o'clock at noon?

Fa. They do; and hence the astronomical day begins 12 hours later than according to common reckoning: so that the declination, longitude, latitude, &c., of the sun, moon, and planets, are always put down for 12 o'clock at noon of the day to which they are opposite. Thus the sun's declination for the 17th of January at 12 o'clock is 20° 48′ South.

Ch. Is that because it is the commencement of the astronomical day, commonly called noon?

Fa. It is. The next three columns contain the moon's declination, the time of her rising and setting, and the time of her *southing,* that is, when she comes to the meridian, or South part of the heavens.

Ch. Does she not come to the South at noon, as well as the sun?

Fa. No; the moon never comes to the meridian at the

same time as the sun, except at the time of new moon, which takes place at every new moon, as you may see by casting your eye down the several columns in the Ephemeris which relate to the moon's southing.

Ja. What is implied in the column by the words "*clock before the sun,*" and "*clock after the sun?*"

Fa. A full explanation of that must be deferred till we come to speak of the *equation of time:* at present it will be sufficient for you to know that if you are in possession of a very accurate and well-regulated clock, and also of an excellent sun-dial, they will be together only four days in a year. Now, this seventh column in the Ephemeris points out how much the clock is before the sun, or the sun before the clock, for every day. On *Twelfth-day*, 1822, for instance, the clock is *faster* than the sun by 6′ and 7″: but if you turn to *May-day*, you will find that the clock is 3′ 2″ slower than the sun. The time exhibited by the sun-dial is called *Solar* or *true* time, and that of a well-regulated watch or clock, *mean* time.

Ja. On what days in the year are the clock and sun-dial together?

Fa. About the 16th of April; the 15th of June; the 1st of September; and Christmas-day.

Ch. By this table, then, we may regulate our clocks and watches.

Ja. In what manner, Charles?

Ch. Examine, on any particular day, the clock or watch, and the sun-dial at the same time; say 12 o'clock; and observe whether the difference between them answers to the difference set down in the table, opposite to the day of observation. Thus, on the 12th of March, 1822, the clock did not show true time, unless it was 10′ 3″ before the dial; or when the dial marks 12 o'clock, it must have been 10′ 3′ past 12 by the clock or watch.

Fa. Perfectly correct; let us now proceed to the next page. The first three *short* columns, relating only to the duration of day-light and twilight, require no explanation: the fourth we shall pass over for the present; and the remaining five give the *latitude* of the planets.

Ja. What do you mean by the latitude, Papa?

Fa. The latitude of any heavenly body is its distance from

the *ecliptic* north or south. The latitude of *Venus*, on New-year's Day, 1822, was 1° 1′ South.

Ch. Then the *latitude* of heavenly bodies has the same reference to the *ecliptic*, as *declination* has to the equator?

Fa. It has.

Ja. But I do not see any table of the sun's latitude.

Fa. I dare say your brother can give you a reason for this.

Ch. As the latitude of a heavenly body is its *distance from* the ecliptic, and as the sun is always in the ecliptic, he can therefore have no latitude.

Fa. The *longitude* of the sun and planets is the only thing in this page that remains to be explained. The longitude of a heavenly body is its distance from the first point of the sign Aries; and it is measured on the ecliptic. It is usual, however, as you observe in the Ephemeris, to express the longitude of a heavenly body by the degree of the sign in which it is. In this way the sun's longitude on the 1st of January, 1822, was in Capricorn, 10° 35′ 48″; that of the moon in Aries, 17° 44′: and so on.

Ch. There are some short columns at the bottom of the former page that you have omitted, and likewise one of the moon's parallax; what do they mean?

Fa. The use of these will be better understood when we come to converse respecting the moon and planets. *Heliocentric* longitude, also, I will explain by and by.*

QUESTIONS FOR EXAMINATION.

What book is necessary in studying the heavens? — Of what use is the Ephemeris?—Do you know the characters and names of the twelve signs of the Zodiac? —What is the Zodiac, and from whence is the term derived? — Repeat Dr. Watts's lines in which the signs of the Zodiac are enumerated. — What are the names of the planets? and draw the character belonging to each. — What do you mean by the declination of a heavenly body? — When do astronomers begin their day? — Which begins first, the common or the astronomical day? — When does the moon come to the meridian at the same time with the sun? — How often does a well regulated clock and the sun by the dial show the same time? — What are the four days in the year when the clock and dial are together? — Can you tell me how to regulate my watch on any day by means of a good dial and the table contained in the Ephemeris? — What is meant by the latitude of a heavenly body? — To what does the latitude of heavenly bodies refer? — Has the sun any latitude, and if not, what is the reason? — What is the longitude of a heavenly body, and on what line is it measured?

* See Conversation XX.

CONVERSATION V.

OF THE SOLAR SYSTEM.

Father. We will now proceed to the description of the *Solar System.*

Ja. Of what does that consist, Papa?

Fa. It consists of the sun and planets, with their satellites or moons. It is called the *Solar System*, from *Sol*, the sun, because the sun is supposed to be fixed in the centre, while the planets, of which our earth is one, revolve round him at different distances.

Ch. But are there not some people who believe that the sun goes round the earth?

Fa. Yes; it is an opinion embraced by the generality of persons not accustomed to reason on these subjects. It was adopted by Ptolemy, who supposed the earth to be perfectly at rest, and the sun, planets, and fixed stars to revolve about it every twenty-four hours.

Ja. And is not that the most natural supposition?

Fa. If the sun and stars were, in comparison with the earth, but small bodies, and were situated at no very great distance from it, then the system maintained by Ptolemy and his followers might appear the most probable.

Ja. Are the sun and stars, then, very large bodies?

Fa. The sun is more than a million times larger than the earth which we inhabit; and many of the fixed stars are probably much larger than he is.

Ch. What is the reason, then, that they appear so small?

Fa. This appearance is caused by the immense distance there is between us and these bodies. It is known with certainty, that the sun is more than ninety-five millions of miles distant from the earth; and the nearest fixed star is probably more than two hundred thousand times further from us than even the sun himself.

Ch. But we can form no conception of such distances.

Fa. We talk of millions with as much ease as of hundreds or tens; but it is not, perhaps, possible for the mind to form any adequate conceptions of such immense distances; yet several methods have been adopted to assist its comprehen-

sion. You have some idea of the swiftness with which a cannon-ball proceeds from the mouth of the gun.

Ja. I have heard that it flies at the rate of eight miles in a minute.

Fa. And you know how many minutes there are in a year.

Ja. That is easily ascertained by multiplying 365 days by 24 for the number of hours, and that product by 60, for the number of minutes, which will amount to 525,600 in a year.

Fa. Now, if you divide the distance of the sun from the earth by the number of minutes in a year, multiplied by 8, because the cannon-ball travels at the rate of eight miles in a minute, you will know how long a body issuing from the sun with the velocity of a cannon-ball would require to reach the earth.

Ch. If I divide 95,000,000 by 525,600, multiplied by 8, or 4,204,800, the answer will be more than 22, the number of years taken for the journey.

Fa. Is it, then, probable that bodies so large, and at such distances from the earth, should revolve round it every day?

Ch. I do not think it is. Will you, Papa, go on with the description of the *Solar System?*

Fa. I will. According to this system, the sun is in the centre, about which the planets revolve from *West to East,* according to the order of the signs in the ecliptic; that is, if a planet is seen in Aries, it advances to Taurus, then to Gemini, and so on.

Fig. 2.

Ja. How many planets are there revolving round the sun?

Fa. At present there have been discovered twenty-three. c is the sun, the nearest to which, *Mercury,* revolves in the circle *a:* next to him is the beautiful planet *Venus,* who performs her revolution in the circle *b:* then comes

the *Earth*, *t;* next to which is *Mars*, *e;* between the orbit of *Mars* and the next circle *f*, denoting the orbit of *Jupiter*, we have fifteen of the minor or ultra-zodiacal planets—viz., *Flora*, *Victoria*, *Vesta*, *Metis*, *Iris*, *Hebe*, *Parthenope*, *Astræa*, *Egeria*, *Irene*, *Eunomia*, *Juno*, *Ceres*, *Pallas*, and *Hygeia;* after *Jupiter* comes *Saturn* in *g;* far beyond him the planet *Uranus* performs his revolution in the circle *h;* and still further beyond him, *Neptune*. I have omitted to represent several of these planets in the diagram, to prevent confusion.

Ja. What do the smaller circles represent which are attached to several of the first?

Fa. They are intended to represent the *orbits* of the several satellites or moons belonging to some of the planets.

Ja. What do you mean by the orbit?

Fa. The path described by a planet in its motion round the sun, or that of a moon round its primary planet, is called its *orbit;* it is derived from the Latin word *orbis*, a "circle." Look to the orbit of the earth (fig. 2,) *d*, and you will see a little circle, which represents the orbit around which our moon performs its monthly journey.

Ch. Has not *Mercury* or *Venus* any moon?

Fa. None have ever been discovered belonging either to Mercury, Venus, or Mars. Jupiter, as you observe by the figure, has four moons: Saturn has seven: and Uranus has six, which, from want of room, are not drawn in the engraving.

Ch. The *Solar System*, then, consists of the sun as a centre, round which revolve *twenty-three* planets, and *eighteen* satellites or moons. Are there no other bodies belonging to it?

Fa. Besides these, there are comets, which make their appearance occasionally; and it would be wrong to affirm positively, that there can be no other planets belonging to the Solar System, since, as I shall tell you presently, one of those above enumerated was discovered last year only.

Ch. Please to inform us why *Uranus* was also named the *Georgium Sidus* and *Herschel*.

Fa. Willingly. The planet *Uranus* was discovered by Dr. Herschel, and it received his name in honour of its discoverer, to whose industry and genius astronomical science is indebted for many other important discoveries. Dr. Herschel

was one of those extraordinary men who raise themselves from very humble situations in life to notice and honour. He was fortunate in obtaining the patronage of George III., under whose auspices he was enabled to pursue his studies, and bring to maturity those discoveries which his vast mind had contemplated. In gratitude to his patron, he gave to the newly-found planet the name of the *Georgium Sidus*, or *George's Planet*; but the world considered the honour of the discovery as due to Dr. Herschel, and therefore named it, after himself, the planet *Herschel*. The name *Uranus* (the father of *Saturn*) was proposed by Professor Bode of Berlin, and is that by which this planet is now generally known.

Ch. Which are the newly-discovered planets, by whom were they respectively discovered, and when?

Fa. CERES was discovered by M. Piazzi, of Palermo, in Sicily, on the 1st of Jan. 1801. PALLAS was discovered by Dr. Olbers, of Bremen, on the 28th of March, 1802, who also discovered VESTA, on the 29th of March, 1807; JUNO was discovered by Prof. Harding, of Lilienthal, near Bremen, on the 1st of Sept. 1804; ASTRÆA and HEBE, by Prof. Hencke, on the 8th of December, 1845, and 1st of July, 1847, respectively; NEPTUNE, by Mr. Adams, M. Leverrier, and M. Gallé conjointly; IRIS, on the 13th of Aug. 1847, and FLORA, on the 18th of Oct. 1847, by Mr. Hind; METIS, by Mr. Graham, on the 25th of April, 1848; HYGEIA, by M. de Gasparis, on the 12th of April, 1849; PARTHENOPE, by the same, on the 11th of May, 1850; VICTORIA, by Mr. Hind, on the 13th of Sept., 1850; EGERIA, by M. de Gasparis, on the 2nd of Nov., 1850; IRENE, by Mr. Hind, on the 19th of May, 1851; and EUNOMIA, by M. de Gasparis, on the 29th of July, 1851.

The planets are pretty readily distinguished from the fixed stars, when attentively watched from night to night by the changes in their relative situations. In some these changes take place rapidly, in others much more slowly. Four of them—Venus, Mars, Jupiter, and Saturn—are remarkably large and brilliant; another, Mercury, is also visible to the naked eye, but is seldom conspicuous. Uranus is scarcely distinguishable without a telescope, and the others are invisible to the naked eye. All of them make the entire tour of the heavens, and, with the exception of the telescopic planets,

perform their movements within that zone of the heavens called the zodiac. It is highly probable, however, that many, if not all, the fixed stars are also in a state of motion, although too slow to be perceptible, unless by means of very delicate observations, continued during a long series of years. Hence the term fixed stars, in regard to planets, must be received in a comparative, not absolute, sense.

QUESTIONS FOR EXAMINATION.

Of what does the solar system consist?—What was the system of Ptolemy?—How large is the sun?—Why do the heavenly bodies, which are so immensely large, appear so small?—At what distance is the sun from the earth? — Are the fixed stars further from us than the sun?—At what rate does a cannon ball proceed from the mouth of a gun?—How long would a cannon ball with the same velocity be coming from the sun to the earth?—How is the sun situated?—Which way do the planets move, and how many are there?—What is the meaning of the term orbit?—Can you explain to me the various parts of fig. 2?—To which of the planets are there satellites or moons, and to which not?—By whom was this system first adopted in ancient and modern times?—Who discovered the minor planets, and what are the dates?—How are the planets distinguished from the fixed stars?

CONVERSATION VI.

OF THE FIGURE OF THE EARTH.

Father. Having, in my last conversation, given you a description of the Solar System in general, we will now proceed to consider each of its parts separately, and since we are most of all concerned with the EARTH, we will begin with that body.

Ja. You promised to explain to us, Papa, why the earth is in the form of a globe, and not a mere extended plane, as it appears to common observation.

Fa. Yes, I did. Suppose, then, you were standing by the sea-shore, on a level with the water, and at a very considerable distance, as far as the eye could reach, you observed a ship approaching: what ought to be its appearance, supposing the surface of the sea to be a flat plane?

Ch. We should, I think, see the whole ship at once; that is, the hull would be visible as soon as the top-mast.

Fa. It certainly must, or indeed rather sooner; because the body of the vessel being so much larger than a slende mast, it must necessarily be visible at a greater distance.

Ja. Yes; I can see the steeple of a church at a mile,

greater distance than I can discern the small weather-cock which is upon it; and that I can perfectly see long before I can descry the iron conductor which is fixed at the extremity of the tower.

Fa. Well; but the top-mast of a vessel at sea is always seen some little time before the hull of the vessel can be discerned. Now, if the surface of the sea be globular, this must be so; because the water, partaking of the rotund shape of the earth between the vessel and the eye of the spectator, will hide the body of the ship for some time after the pendant at the mast-head is seen.

Ch. In the same way as if any high building were situated on one side of a hill, and I was walking on the opposite side, the upper part would come first in sight, and as I advanced towards the summit, the other parts would come successively into view.

Fa. Your illustration is quite in point. The same will be experienced by two persons walking up a hill on opposite sides: they will perceive each other's heads first; and as they advance to the top, the other parts of their bodies will become visible. With respect to the ship, the following figure will convey the idea very completely. Suppose *c b e a* represent a

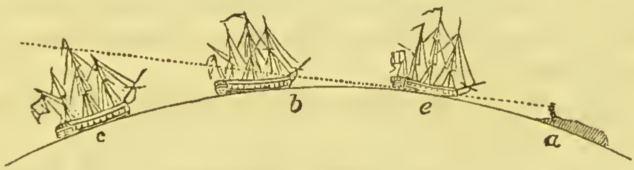


Fig. 3.

small part of the curved surface of the sea; if a spectator stand at *a*, while a ship is at *c*, only a small part of the mast will be visible to him; but as it advances, more of the ship is seen, till it arrives at *e*, when the whole will be in sight.

Ch. When I stood by the sea-side, the water did not appear to me to be curved.

Fa. Perhaps not: but its convexity may be discovered upon any still water, as upon a river extending a mile or two in length; for you might see a very small boat at that distance while standing upright; but if you stoop down, so as to bring your eye near the water, you will find the surface of it rising in such a manner as to cover the boat, and intercept its view completely. Another proof of the globular figure of the earth

is, that it is necessary for those who are employed in cutting canals to make a certain allowance for the convexity; since the true level is not a straight line, but a curve which falls eight inches below it in the mile.

Ch. I have heard of people sailing *round* the world, which is another proof, I imagine, of the globular figure of the earth.

Fa. It is a well-known fact that navigators have set out from a particular port, and, by steering their course continually westward, have at length arrived at the same place whence they first departed. Now, had the earth been an extended plane, the longer they had travelled, the further must they have been from home.

Ch. How is it known that they continued the same course? Might they not have been driven round at sea?

Fa. By means of the Mariner's Compass (the history, properties, and uses of which, I will explain very particularly in a future part of our lectures) the method of sailing on the ocean by one certain track is as sure as travelling on the high road from London to York. By the aid of this instrument, Ferdinand Magellan made a voyage, in the year 1519, from the western coast of Spain, continuing westward, till he arrived, after 1124 days, at the same port whence he set out. The same, with respect to Great Britain, was done by our own countrymen, Sir Francis Drake, Lord Anson, Captain Cook, and many others.

Ch. Is, then, the ordinary terrestrial globe a just representation of the earth?

Fa. It is; with this small difference—that the artificial globe is a perfect sphere; whereas the earth is a spheroid; that is, in the shape of an orange; the diameter from *pole to pole* being about 37 miles shorter than that at the *Equator.*

Ch. But do not the mountains affect the earth's globular shape?

Fa. What the earth loses of its sphericity by mountains and valleys, is very inconsiderable; the highest mountain bearing so little proportion to its bulk as scarcely to be equivalent to the minutest protuberance on the surface of an orange.

Ja. Was not the earth for some time thought to be a circular plane?

Fa. For a long period of ages, it was supposed that the

surface of the earth was a large circular plane, indefinitely extended, and bounded on all sides by the sky. This opinion was long entertained by the illiterate, and in the different periods in the history of science was believed and taught by the learned.

Moreover, all the proofs we have here mentioned are confirmed and illustrated by an eclipse of the moon, which presents to us an ocular demonstration of the earth's rotundity.

Ch. What is a lunar eclipse, Papa?

Fa. A lunar eclipse is caused by the intervention of the body of the earth between the sun and moon, in which case the shadow of the earth falls upon the moon. And in every eclipse of this kind, which is not total, the obscure part always appears to be bounded by a circular line; the earth itself, for that reason, must be spherical; it being evident, that nothing but a spherical body can, in all situations, cast a circular shadow; and, as we have just remarked, the mountains and valleys which diversify its surface take little or nothing from its globular shape, for they bear no more proportion to its magnitude than the smallest grain of sand does to a common globe.

Ch. Have you not said that navigation very much depends on a correct knowledge of the sphericity of the earth?

Fa. On the knowledge of this spherical figure of the earth the art of navigation in a great measure depends, and all the great voyages of discovery which have been made were undertaken in consequence of the knowledge of this fact. Had mankind remained unacquainted with this discovery, the circumnavigation of the globe would never have been attempted; vast portions of the habitable world would have remained unknown and unexplored; no regular intercourse would have been maintained between the various tribes of the human race; and, consequently, the blessings of divine revelation would never have been communicated to the greater part of the Gentile world, at least as far as our finite reason can suppose.

Ja. What are the poles, Papa?

Fa. In the artificial globe (fig. 4.) there is an axis, N S, about which it turns. The two extremities or ends of this axis, N and S, are called the poles.

Ch. Is there any axis belonging to the earth?

Fa. No: but as we shall by and by show that the earth turns round once in every 24 hours, so astronomers imagine an axis upon which it revolves as upon a centre; the extremities of which imaginary axis are the poles of the earth, of which N, the north pole, points at all times exactly to *p*, the north pole of the heavens which we have already described (fig. 1.), and which is, as you recollect, within two degrees of the polar star.

Ja. And how do you define the *equator?*

Fa. The *equator*, AB, is an imaginary circle passing round the earth, perpendicular to the axis N S, and at equal distances from the poles.

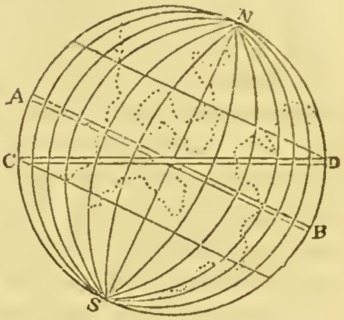


Fig. 4.

Ch. And I think you told us, that if we imagined this circle to extend every way to the fixed stars, it would form the *celestial equator*.

Fa. I did. It is also called the *equinoctial;* and you must not forget that, in this case, it would cut the circle of the *ecliptic* C D in two points.

Ja. Why is the *ecliptic* marked on the terrestrial globe, since it is a circle peculiar to the heavens?

Fa. Though the *ecliptic* be peculiar to the heavens, and the *equator* to the earth, yet they are both drawn on the terrestrial and celestial globes, in order, among other things, to show the relative positions of these imaginary circles.

I shall now conclude our present conversation with observing that, besides the proofs adduced of the globular form of the earth, there are others equally conclusive, which will be better understood when we have made a little further progress.

QUESTIONS FOR EXAMINATION.

How is it proved that the earth is of a globular figure, and not a mere plane? — Explain this by fig. 3. — Why does not the sea appear to the eye to be curved? — How does the method adopted in cutting canals prove the globular figure of the earth? — Is there any other proof that the earth is round? — How can it be known whether a ship has sailed round the earth? — Is the earth a perfect sphere, like the artificial globe? — How much do the two diameters of the earth differ from one another, and which is the longer of the two? — What are the extremities of the earth's axis called? — What is the equator?—

Why is the ecliptic marked on the terrestrial globe? — Of what shape did the ancients consider the earth? — What is the true shape? — What proofs have you to support this opinion? — What is a lunar eclipse? — A solar eclipse? — What science depends upon a knowledge of the spherical form of the earth? — What great results have arisen from this knowledge? — What proofs have you that the sun is stationary? — And that the earth moves round the sun? — Explain them to me.

CONVERSATION VII.

OF THE DIURNAL MOTION OF THE EARTH.

Father. Well, children, are you satisfied that the earth on which you tread is a globular body, and not a mere extended plane?

Ch. Admitting the facts which you mentioned yesterday; viz., that the top-mast of a ship at sea is always visible before the body of the vessel comes into sight; that navigators have repeatedly, by keeping the same course, sailed round the world; and that persons employed in digging canals can only execute their work with effect by allowing for the supposed globular shape of the earth; it is evident that the earth cannot be a mere extended plane.

Ja. But as all these facts can be accounted for upon the supposition that the earth is a globe; you therefore conclude it is a globe. This is, I believe, the nature of the proof?

Fa. It is. Let us now advance one step further, and show you that this globe turns on an imaginary axis every twenty-four hours; thereby causing the succession of day and night.

Ja. I shall be surprised if you are able to afford such satisfactory evidence of the daily motion of the earth as of its globular form.

Fa. I trust, that the arguments on this subject will be quite as convincing, and that, before we part, you will admit that the apparent motion of the sun and stars is occasioned by this diurnal motion of the earth.

Ch. I shall be glad to hear how this can be proved; for if, in the morning, I look at the sun rising, it appears in the East; at noon it has travelled to the South; and in the evening I see it set in the western part of the heavens.

Ja. Yes; and we observed the same last night (March the first) with respect to *Arcturus;* for, about eight o'clock, it

had just risen in the north-west part of the heavens, and when we went to bed, two hours after, it had ascended a considerable height in the heavens, evidently travelling towards the West.

Fa. It cannot be denied that the heavenly bodies appear to rise in the East and set in the West; but the *appearance* will be the *same* to us, whether those bodies revolve about the earth while that stands still, or they stand still while the earth turns on its axis the contrary way.

Ch. Will you explain this, Papa?

Fa. Suppose *g r c b* (fig. 5.) to represent the earth, *t* the centre on which it turns from West to East, according to the order of the letters *g r c b*. If a spectator, on the surface of the earth at *r*, see a star at *h*, it will appear to him to have just risen. If, now, the earth be supposed to turn on its axis a fourth part of a revolution, the spectator will be carried from *r* to *c*, and the star will be then just over his head. When another fourth part of the revolution is completed, the spectator will be at *b*; and to him the star at *h* will be setting, and will not be visible again till he arrives, by the rotation of the earth, at the station *r*.

Ch. To the spectator, then, at *r*, the appearance would be the same, whether he turned with the earth into the situation *b*, or the star at *h* had described, in a contrary direction, the space *h z o* in the same time.

Fa. It certainly would.

Ja. But if the earth really turned on its axis, should we not perceive the motion?

Fa. The earth, in its diurnal rotation, being subject to no impediments by resisting obstacles, its motion cannot affect the senses. In the same way ships on a smooth sea are frequently turned entirely round by the tide, without the knowledge of those persons who happen to be busy in the cabin or between the decks.

Ch. That is because they pay no attention to any other object but to those about the vessel in which they are; and every part of which moves with themselves.

Ja. But if, while the ship is turning without their knowledge, they happen to be looking at fixed distant objects, what will be the appearance?

Fa. To them those objects which are at rest will appear to

be turning round the contrary way. In the same manner we are deceived in the motion of the earth round its axis; for if we attend to nothing but what is connected with the earth, we cannot perceive a motion of which we partake ourselves; and if we fix our eyes on the heavenly bodies, the motion of the earth being so easy, they will appear to be turning in a contrary direction to the real motion of the earth.

Ch. I have sometimes seen a sky-lark hovering and singing over a particular field for several minutes together: now, if the earth is continually in motion while the bird remains in the same part of the air, why do we not see the field, over which he first ascended, pass from under him?

Fa. Because the atmosphere, in which the lark is suspended, is connected with the earth, partakes of its motion, and carries the lark along with it; and, therefore, independently of the motion given to the bird by the exertion of its wings, it has another, in common with the earth, yourself, and all things on it; and, thus being common to us all, we have no means of ascertaining it by the senses. The rotation of the earth on its axis, the smoothness of its motion, and its effect on the atmosphere, are described by Milton in three lines—

> . . . . . . That spinning sleeps
> On her soft axle as she paces even,
> And bears us swift with the smooth air along.

Ja. Though the motion of a ship cannot be observed without objects at rest to compare with it, yet I cannot help thinking that if the earth moved we should be able to discover it by means of the stars, if they are fixed.

Fa. Do you not remember once sailing very swiftly on the river, when you told me that you thought all the trees, houses, &c. on its banks were in motion?

Ja. I now recollect it well; and I had some difficulty in persuading myself that it was not so.

Ch. This brings to my mind a still stronger deception of this sort. When travelling with great speed on a railroad, or in a coach, I can scarcely help thinking, but that the trees and hedges are running away from us, and not we from them.

Fa. I will mention another curious instance of this kind. If you ever happen to travel rather swiftly on a railway, by the side of a field ploughed into long narrow ridges, which

are perpendicular to the rails, you will think that all the ridges are turning round in a direction contrary to that of the carriage. These facts may satisfy you that the appearances will be precisely the same to us, whether the earth turn on its axis from West to East, or the sun and stars move from East to West.

Ja. They do so: but which is the most natural conclusion?

Fa. This you shall determine for yourself. If the earth (fig. 4.) turns on its axis in 24 hours, at what rate will any part of the equator A B move?

Ch. To determine this we must find the measure of its circumference, and then dividing this by 24, we shall get the number of miles passed through in an hour.

Fa. Just so. Now, call the semi-diameter of the earth 4000 miles, which is rather more than the true measure.

Ja. Multiplying this by six* will give 24,000 miles for the circumference of the earth at the equator; and this divided by 24 gives 1000 miles for the space passed through in an hour on that line.

Fa. You are right. Now the sun, I have already told you, is 95 millions of miles distant from the earth. Tell me, therefore, Charles, at what rate that body must travel to go round the earth in 24 hours.

Ch. I will: 95 millions multiplied by six, will give 570 millions of miles for the length of his circuit: this divided by 24 gives nearly 24 millions of miles for the space he must travel in an hour to go round the earth in a day.

Fa. Which, now, is the more probable conclusion—either that the earth should have a diurnal motion on its axis of 1000 miles in an hour, or that the sun, which is a million of times larger than the earth, should travel 24 millions of miles in the same time?

Ja. It is certainly more rational to conclude that the earth turns on its axis; the effect of which, you told us, was the alternate succession of day and night.

* To be accurate in the calculation, the mean radius of the earth must be taken at 3964 miles; and this multiplied by 6,28318, will give 24,907 miles for the circumference. Through the remainder of this work, the decimals in multiplication are omitted, in order that the mind may not be burdened with fractions. It seemed necessary, however, in this place to give the true semi-diameter of the earth, and the number (accurate to five places of decimals) by which, if the radius of any circle be multiplied, the circumference is obtained.

Fa. I did. Having now formed some notion of the manner in which the earth moves, we shall easily conceive the motions of all the rest of the planets, and by that means obtain a complete idea of the order and economy of the whole "SYSTEM." And in order to comprehend this readily, nothing more is necessary than to consider the common appearances of the heavens, which are constantly presented to our view, and attend to the results.

Besides this motion of the earth, which is called its *daily motion*, which is the cause of day and night, it has another, called its *annual* or *yearly* motion, which occasions the various vicissitudes of the SEASONS; viz. *winter*, *spring*, *summer*, and *autumn*. And the proofs of this second motion may be easily gathered from celestial appearances, in nearly the same manner as the former. On this and some other points connected with the subject, we will enlarge in our next conversation.

QUESTIONS FOR EXAMINATION.

Repeat the facts adduced in proof of the globular shape of the earth. — Has the earth any motion of its own? — What are the natural appearances with regard to the heavenly bodies? — Can you by fig. 5, show me that the appearance will be the same to us whether those bodies revolve round the earth, or the earth turn about on its axis? — Why do we not perceive the motion of the earth? — What will be the appearance of distant objects to a person standing in a ship while the vessel is turning about? — Why does not a particular spot of the earth appear to move from under a lark which is apparently stationary in the air, or nearly so? — What are Milton's lines on the motion of the earth? — Do you recollect any deceptions in the sight with regard to moving objects? — With what velocity does the equator move in the diurnal motion of the earth? — If the sun goes round the earth in 24 hours, at what rate must he travel? — What is the effect of the earth's turning on its axis?

CONVERSATION VIII.

OF DAY AND NIGHT.

James. You are now, Papa, going to apply the rotation of the earth about its axis to the succession of day and night, are you not?

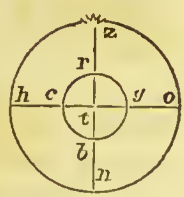


Fig. 5.

Fa. Yes; and for this purpose, suppose *grcb* to be the earth, revolving on its axis, according to the order of the letters; that is, from *g* to *r*, *r* to *c*, &c. If the sun be fixed

in the heavens at *z*, and a line, *ho* be drawn through the centre of the earth *t*, it will represent that circle, which, when extended to the heavens, is called the *rational horizon.*

Ch. In what does this differ from the *sensible horizon ?*

Fa. The *sensible horizon* is that circle in the heavens which bounds the spectator's view, and which is greater or less according to his relative position. For example:—an eye placed at *five* feet above the surface of the earth, sees $2\frac{3}{4}$ miles every way: but if it be at 20 feet high, that is, 4 times th height, it will see $5\frac{1}{2}$ miles, or twice the distance.

Ch. Then the *sensible* horizon differs from the *rational* in this; that the *former* is seen from the surface of the earth, and the *latter* is supposed to be viewed from its centre.

Fa. You are right: and the rising and setting of the sun and stars are always referred to the rational horizon.

Ja. Why so? They appear to rise and set as soon as they get above, or sink below, that boundary which separates the visible from the invisible part of the heavens.

Fa. They do not, however: and the reason is this; that the distance of the sun and fixed stars is so great in comparison of 4000 miles, (the difference between the surface and centre of the earth,) that it can scarcely be taken into account.

Ch. But 4000 miles seem to me an immense space.

Fa. Considered individually it is so; but when compared with 95 millions of miles, the distance of the sun from the earth, the distance is comparatively nothing.

Ja. But do the rising and setting of the moon, which is at the distance of 240 thousand miles, have respect also to the rational horizon?

Fa. Certainly: for 4000 compared with 240 thousand, bear only the proportion of 1 to 60. Now, if two spaces were marked out on the earth in different directions, the one 60 and the other 61 yards, should you at once be able to distinguish the greater from the less?

Ch. I think not.

Fa. Just in the same manner does the distance of the centre from the surface of the earth vanish in comparison of its distance from the moon, with a slight exception, which we shall explain hereafter.

Ja. We must not, however, forget the succession of day and night.

Fa. Well, then; if the sun be supposed at *z*, it will illuminate by its rays all that part of the earth that is above the horizon, *ho*: to the inhabitants at *g*, its western boundary, it will appear just rising: to those situated at *r*, it will be noon; and to those in the eastern part of the horizon, *c*, it will be setting.

Ch. I see clearly why it should be noon to those who live at *r*, because the sun is just over their heads; but it is not so evident that the sun must appear rising and setting to those who are at *g* and *c*.

Fa. You are satisfied that a spectator cannot, from any place, observe more than a semi-circle of the heavens at any one time. Now what part of the heavens will the spectator at *g* observe?

Ja. He will see the concave hemisphere *z o n*.

Fa. The boundary to his view will be *n* and *z*: will it not?

Ch. Yes; and consequently the sun at *z* will to him be just coming into sight.

Fa. Then, by the rotation of the earth, the spectator at *g* will in a few hours come to *r*, when, to him, it will be noon; and those who live at *r* will have descended to *c*. Now, what part of the heavens will they see in this situation?

Ja. The concave hemisphere *nhz*: and *z* being the boundary of their view one way, the sun will to them be setting.

Fa. Just so. After which they will be turned away from the sun, and consequently it will be night to them till they come again to *g*. Thus, by this simple motion of the earth on its axis, every part of it by turns is enlightened and warmed by the cheering beams of the sun.

Ch. Then I perceive that as the sun retires in the evening, his light gently fades away in the west, and night succeeds with all her myriads of stars. If we follow the course of the stars, we see them also rising in the east, and moving in regular succession across the heavens to the west, where, one by one, they set and disappear. This solemn procession continues for several hours, till at length the morning light again begins to dawn, and another day succeeds. Thus all the heavenly bodies *appear* to our senses to move regularly round the earth once in 24 hours. This, however, is only in appearance, for in reality the sun and stars are stationary, and day and night are caused by the revolution of the earth

round her own axis, once in 24 hours, as before explained. Does this motion of the earth account also for the apparent motion of the fixed stars?

Fa. It is owing to the revolution of the earth round its axis that we imagine that the whole starry firmament revolves about the earth in 24 hours.

Ja. If the heavens appear to turn on an axis, must there not be two points; namely, the extremities of that imaginary axis, which always keep their position?

Fa. Yes; we must be understood to except the two celestial poles, which are opposite to the poles of the earth; consequently, each fixed star appears to describe a greater or a smaller circle round these, according to its distance from those celestial poles. This motion of the earth may be familiarly illustrated by passing a wire for an axis through an orange, or any round body; then hold it before a lamp, so that the light may shine equally on both poles at once. The side towards the lamp will represent *day*, the other, being in the shadow of its own body, will represent *night.*

If the globe or orange be turned round on its axis, it will be seen that one part of the surface is constantly passing out of its own shadow into the light, which represents morning, or the rising of the sun; the opposite side, as it passes out of the light into the dark part, represents evening, or the setting of the sun. By this explanation it is readily shown why the heavenly bodies *appear* to move round the earth, rather than the earth's turning on its own axis.

Ch. When we turn from that hemisphere in which the sun is placed, do we immediately gain sight of the other, in which the stars are situated?

Fa. Every part of the heavens is beautified with these glorious bodies, both the hemisphere where the sun is, and that where he is not.

Ja. If every part of the heavens be thus adorned, why do we not see them in the day time as well as in the night?

Fa. Because, in the day time, the sun's rays are so powerful, as to render *those* coming from the fixed stars invisible. But if you ever happen to go down into any very deep mine, or coal-pit, where the rays of the sun cannot reach the eye, and it be a clear day, you may, by looking up to the heavens, see the stars at noon as well as in the night.

Ch. If the earth always revolves on its axis in 24 hours, why does the length of the days and nights differ in different seasons of the year?

Fa. This depends on other causes connected with the earth's *annual* journey round the sun, upon which we will converse the next time we meet.

QUESTIONS FOR EXAMINATION.

Explain, by means of fig. 5, how the rotation of the earth upon its axis produces day and night. — What is the sensible horizon, and upon what does its extent depend? — What is the rational horizon, and what does it differ from the sensible? — To which of these do the rising and setting of the stars depend, and why? — Why does the distance of the centre from the surface of the earth appear to vanish in comparison of its distance from the moon and other heavenly bodies? — Turn to the figure: When the sun is at *z*, which part of the earth will be illuminated by its rays? — To what part of the earth will it be rising, and to what other part will it be setting? — Explain the reasons of this. — What is the consequence of the earth's diurnal motion? Will the motion of the earth account for the apparent motion of the fixed stars? — Round what points in the heavens do the fixed stars appear to move? — What is the occasion of night? Are there stars in every part of the heavens? — Repeat Dr. Young's lines on this subject. — Why are the stars above us invisible in the day? — Is there any mode of getting a glimpse of the stars by day?

CONVERSATION IX.

OF THE ANNUAL MOTION OF THE EARTH.

Father. Besides the *diurnal* motion of the earth, by which the succession of day and night is produced, it has another, called its *annual* motion; which is the journey it performs round the sun in 365 days, 5 hours, 48 minutes, and 49 seconds.

Ch. Are the different seasons to be accounted for by this motion of the earth?

Fa. Yes; it is the cause of the different lengths of the days and nights, and consequently of the different seasons; viz. *Spring*, *Summer*, *Autumn*, and *Winter*.

Ja. How is it known that the earth makes this annual journey round the sun?

Fa. I told you in our last conversation, that through the shaft of a very deep mine, the stars are visible in the day as well as in the night, as they are also by means of a telescope properly fitted for the purpose: so that in this way the sun

and stars may be made visible at the same time. Now, if the sun be seen in a line with a fixed star to-day, at any particular hour, it will, in a few weeks, by the motion of the earth, be found considerably to the East of him: and if the observations be continued through the year, we shall be able to trace him round the heavens to the same fixed star from which we set out: consequently, the sun must have made a journey round the earth in that time, or the earth round him.

Ch. And the sun, being a million of times larger than the earth, you will say that it is more natural that the smaller body should go round the larger than the reverse.

Fa. That is a very good argument; and it may be stated in a much stronger manner. The sun and earth mutually attract one another; and, since they are in equilibrium by this attraction, you know, that their *momenta* must be equal:* therefore the earth, being the smaller body, must make up by its motion what it wants in the quantity of its matter; and, of course, it must be that which performs the journey.

Ja. But if you refer to the principle of the lever to explain the mutual attraction of the sun and earth, it is evident, that both bodies must turn round some point as a common centre.

Fa. And that is the centre of gravity which is common to the two bodies. Now, this point between the earth and sun is within the surface of the latter body.

Ch. I understand how this is: because the centre of gravity between any two bodies must be as much nearer to the centre of the larger body than the smaller, as the former contains a greater quantity of matter than the latter.

Fa. You are right: but you will not conclude that, because the sun is a million of times larger than the earth, it therefore contains a quantity of matter greater by a million of times than that contained in the earth.

Ja. Is it then known that the earth is composed of matter more dense than that which composes the body of the sun?

Fa. The earth is composed of matter four times denser than that of the sun; and hence the quantity of matter in the sun is between two and three hundred thousand times greater than that which is contained in the earth.

Ch. Therefore, for the *momenta* of these two bodies to be

* See Conversation XIV.

equal, the velocity of the earth must be between two and three hundred thousand times greater than that of the sun.

Fa. It must: and to effect this, the centre of gravity between the sun and earth must be so much nearer to the centre of the sun, than it is to the centre of the earth, as the former body contains a greater quantity of matter than the latter: and hence it is found to be several thousand miles within the surface of the sun.

Ja. I now clearly perceive that, since one of these bodies revolves about the other in the space of a year, and that they both move round their common centre of gravity, it must of necessity be the earth which revolves round the sun, and not the sun round the earth. Yet how is it that the sun by its attractive force does not draw the earth into itself?

Fa. This circular motion of the earth is produced by two forces: which counteract each other in just proportions. The centripetal attraction draws it to the sun, and the projectile or centrifugal force carries it from the sun, so that it takes its path between the two, as would be illustrated by the diagonal of a parallelogram: but the continued action of these forces produces that orbit which we term circular, or more properly elliptical. To suppose moreover that the sun moves round the earth is too absurd to be admitted by any one of com mon capacity or understanding.

QUESTIONS FOR EXAMINATION.

Has the earth any other motion besides that round its axis? — How are the seasons of winter and summer to be accounted for? — Can you tell me how it is ascertained that the earth makes this annual journey round the sun? — Can the same thing be proved by the mutual attraction of the earth and sun? — Do they turn round any common point, and what is that called? — Is the matter of the earth or sun the more dense, and in what proportion? — In what proportion is the quantity of matter greater in the sun than it is in the earth? — How much swifter, then, should the motion of the earth be than that of the sun?

CONVERSATION X.

OF THE SEASONS.

Father. I will now show you how the different seasons are produced by the annual motion of the earth.

Ja. Upon what do they depend, Papa?

Fa. The variety of the seasons depends upon the length of the days and nights, and upon the position of the earth with respect to the sun.

Ch. But if the earth turn round its imaginary axis every 24 hours, ought it not to enjoy equal days and nights all the year?

Fa. This would be the ease if the axis of the earth, N S, were perpendieular to a line, C E, drawn through the eentres of the sun and earth; for then, as the sun always enlightens one half of the earth by its rays; and as it is day, at any given place on the globe, so long as that place continues in the enlightened hemisphere, every part, except the two poles, must, during its rotation on its axis, be one half of its time in the light and the other half in darkness: or, in other words, the days and nights would be equal to all the inhabitants of the earth, exeepting to those who may be living at the poles.

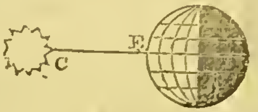


Fig. 6.

Ja. Why do you except the inhabitants at the poles?

Fa. Because the view of the spectator, situated at the poles N and S, must be bounded by the line C E; consequently to him the sun would never appear to rise, or set, but would always be in the horizon.

Ch. If the earth were thus situated, would the rays of the sun always fall vertically on the same part of it?

Fa. They would: and that part would be E Q, the equator; and, as we shall presently show, the heat generated by the sun, being greater or less in proportion as its rays fall more or less perpendicularly upon any body, the parts of the earth about the equator would be scorched up, while those between 40 and 50 degrees on each side of that line and the poles would be desolated by an unceasing winter.

Ja. In what manner is this prevented?

Fa. By the axis of the earth, N S, being inclined about 23 degrees and a half out of the perpendicular, as it is described by Milton.

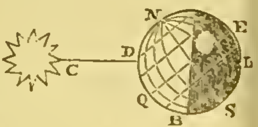


Fig. 7

> . . . . He bade his angels turn askance
> The poles of earth twice ten degrees and more
> From the sun's axle.

In this case you observe that all the parallel cireles, except the

equator, are divided into two unequal parts, having a greater or less portion of their circumferences in the enlightened than in the darkened hemisphere, according to their situation with respect to N, the north, or S, the south pole.

Ch. At what season of the year is the earth represented in this figure?

Fa. At our summer season: for you observe that the parallel circles in the northern hemisphere have their greater parts enlightened, and their smaller parts in the dark. If D L represent that circle of latitude on the globe in which Great Britain is situated, it is evident that about two thirds of it are in the light, and only one third in darkness.

You will remember that *parallels of latitude* are circles on the surface of the earth, or its representative, the terrestrial globe, drawn parallel to the equator.

Ja. Is that the reason why our days, towards the middle of June, are 16 hours long, and the nights but 8 hours?

Fa. It is: and if you look to the parallel next beyond that marked D L, you will see a still greater disproportion between the day and night, and the parallel, N, more north than this, is entirely in the light.

Ch. Is it, then, day there entirely?

Fa. To the whole space between that and the pole it is continual day for some time; the duration of which is in proportion to its vicinity to the pole; and at the pole there is permanent day-light for six months together.

Ja. And during that time it must, I suppose, be night to the people who live at the south pole?

Fa. Yes: the figure shows that the south pole is in darkness; and you may observe that, to the inhabitants living in equal parallels of latitude, the one north, and the other south, the length of the days to the one will be always equal to the length of the nights to the other.

Ch. What then shall we say of those who live at the equator, and consequently have no latitude?

Fa. To them the days and nights are *always* equal, and of course twelve hours each in length: and this is also evident from the figure; for, in every position of the globe, one half of the equator is in the light and the other half in darkness.

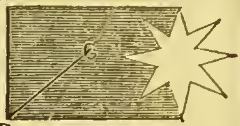
Ja. If, then, the length of the days is the cause of the dif-

ferent seasons, there can be no variety in this respect to those who live at the equator.

Fa. You seem to forget that the change in the seasons depends upon the position of the earth with respect to the sun; that is, upon the *perpendicularity* with which the rays of light fall upon any particular part of the earth, as well as upon the length of the days.

Ch. Does this make any material difference with regard to the heat of the sun?

A



B.

Fig. 8.

Fa. It does. Let AB represent a portion of the earth's surface, on which the sun's rays fall perpendicularly: let BC represent an equal portion, on which they fall obliquely or aslant. It is manifest that BC, though it be equal to AB, receives but half the light and heat that AB does. Moreover, by the sun's rays falling more perpendicularly, they come with greater force, as well as in greater numbers, on the same place.

QUESTIONS FOR EXAMINATION.

Upon what do the different seasons depend? — Why does not the earth enjoy equal days and nights all the year, and under what circumstances would that be the case? — Why are the people at the poles excepted? — In what case would the rays of the sun fall vertically on a particular part of the earth? — Would that be advantageous or otherwise to the earth? — How much is the axis of the earth inclined from the perpendicular? — Explain this by fig. 7.— Why are our days in summer 16 hours long, and in winter only 8? — To whom is this difference still greater? — To what parts of the earth are there six months day and six months night? — To what parts of the earth are the days and nights always equal? — Upon what does the change in the seasons depend? — Show me by fig. 8, how the heat of the sun differs by the mode of its falling upon any particular place.

CONVERSATION XI.

OF THE SEASONS — *continued.*

Father. Let us now take a view of the earth in its annual course round the sun, considering its axis as inclined $23\frac{1}{2}$ degrees to a line perpendicular to its orbit, and keeping, through its whole journey, a parallel direction, and you will find, that according to the situation of the earth in different parts of its orbit, the rays of the sun are presented perpen-

dicularly to the equator, and to every point of the globe, within $23\frac{1}{2}$ degrees of it, both North and South.

This figure (fig. 9) represents the earth in four different parts of its orbit, or as it is situated with respect to the sun in the months of March, June, September, and December.

Ch. The earth's orbit is not made circular in the figure.

Fa. It is nearly circular: but you are supposed to view it from the side B D; and therefore, though almost a circle, it appears to be a long ellipse. All circles appear elliptical in an oblique view, as is evident by looking obliquely at the rim of a basin, at some distance from you. For the true figure of a circle can only be seen when the eye is directly over its centre. You observe that the sun is not in the centre.

Ja. I do: and it appears nearer to the earth in the winter than in the summer.

Fa. We are, indeed, more than three millions of miles nearer to the sun in December than we are in June.

Ch. Is this possible? and yet our winter is so much colder than the summer.

Fa. Notwithstanding this, it is a well-known fact: for it is ascertained that our summer (that is, the time that passes between the vernal and autumnal equinoxes) is nearly eight days longer than our winter, or the time between the autumnal and vernal equinoxes. Consequently, the motion of the earth is slower in the former case than in the latter; and therefore, as we shall see, it must be at a greater distance from the sun. Again, the sun's *apparent* diameter is greater in our winter than in summer; but the apparent diameter of any object increases in proportion as our distance from the object is diminished; and therefore we conclude that we are nearer the sun in winter than in summer. The sun's apparent diameter in winter is $32' \, 35''$; in summer $31' \, 30''$.

Ja. But if the earth is further from the sun in summer than in winter, why are our winters so much colder than our summers?

Fa. Because, first, in the summer, the sun rises to a much greater height above our horizon, and therefore its rays coming more perpendicularly, more of them, as we showed you yesterday, must fall upon the surface of the earth, and come also with greater force; which is the principal cause of our greater summer heat. Secondly, in summer the days are very long,

and the nights short; therefore the earth and air are heated by the sun in the day for a longer period than they are cooled in the night.

Ja. Why have we not, therefore, the greatest heat at the time when the days are longest?

Fa. The hottest season of the year is certainly a month or two after that time: which may be thus accounted for: a body once heated does not grow cold again instantaneously, but gradually: now, as long as more heat comes from the sun in the day than is lost in the night, the heat of the earth and air will be daily increasing: and this must evidently be the case for some weeks after the longest day, both on account of the number of rays which fall on a given space, and also from the perpendicular direction of those rays.

Ja. Will you now explain to us in what manner the change of seasons is produced?

Fa. By referring to the figure you will observe, that in the month of June the north-pole of the earth inclines towards the sun, and consequently brings all the northern parts of the globe more into light than at any other time in the year.

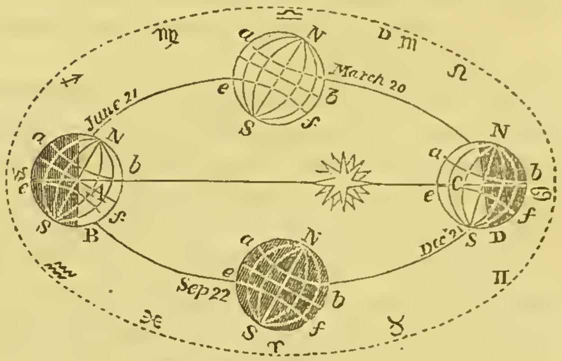


Fig. 9.

Ch. Then to the people in those parts it is summer.

Fa. It is: but in December, when the earth is in the opposite part of its orbit, the north pole declines from the sun, which occasions the northern places to be more in the dark than in the light; and the reverse at the southern places.

Ja. Is it then summer to the inhabitants of the southern hemisphere?

Fa. Yes, it is; and winter to us. In the months of March and September, the axis of the earth does not incline to, nor decline from, the sun, but is perpendicular to a line drawn from its centre. And then the poles are in the boundary of

light and darkness, and the sun being directly vertical to, or over, the equator, makes equal day and night at all places. Now trace the annual motion of the earth in its orbit for yourself, as it is represented in the figure.

Ch. I will, Papa. About the 20th of March the earth is in Libra, and consequently to its inhabitants the sun will appear in Aries, and be vertical to the equator.

Fa. And then the equator, and all its parallels, are equally divided between the light and dark.

Ch. Consequently the days and nights are equal all over the world. As the earth pursues its journey from March to June, its northern hemisphere comes more into light; and on the 21st of that month, the sun is vertical to the tropic of Cancer.

Fa. And you then observe, that all the circles parallel to the equator are unequally divided; those in the northern half have their greater parts in the light, and those in the southern half have their larger parts in darkness.

Ch. Yes; and of course it is summer to the inhabitants of the northern hemisphere, and winter to the southern.

I now trace it to September, when I find the sun vertical again to the equator, and of course, the days and nights are again equal; and following the earth in its journey to December, or when it has arrived at Cancer, the sun appears in Capricorn, and is vertical to that part of the earth called the tropic of Capricorn; and now the southern pole is enlightened, and all the circles on that hemisphere have their larger parts in light; and, of course, it is summer to those parts, and winter to us in the northern hemisphere.

Fa. Can you, James, now tell me, why the days lengthen and shorten, from the equator to the polar circles, every year?

Ja. I will try: because the sun in March is vertical to the equator; and from that time to the 21st of June it becomes vertical successively to all other parts of the earth between the equator and the tropic of Cancer; and, in proportion as it becomes vertical to the more northern parts of the earth, it declines from the southern, and consequently, to the former the days lengthen, and to the latter they shorten. From June to September the sun is again vertical successively to all the same parts of the earth, but in a reverse order.

Ch. Since it is summer to all those parts of the earth where the sun is vertical, (and we find that the sun is vertical twice in the year to the equator and to every part of the globe between the equator and tropics) there must be also two summers in a year to all those places.

Fa. There are: and in those parts near the equator, they have two harvests every year.——But let your brother finish his description.

Ja. From September to December, it is successively vertical to all the parts of the earth situated between the equator and the tropic of Capricorn, which is also the cause of the lengthening of the days in the southern hemisphere, and of their becoming shorter in the northern.

Fa. Can you, Charles, tell me why there is sometimes neither day nor night, for some little time, within the polar circles?

Ch. The sun always shines upon the earth 90 degrees every way; and when he is vertical to the tropic of Cancer, which is $23\frac{1}{2}$ degrees north of the equator, he must shine the same number of degrees beyond the pole, or to the polar circle; and while he thus shines, there can be no night to the people within that polar circle; and, of course, to the inhabitants at the southern polar circle, there can be no day at the same time; for, as the sun's rays reach but 90 degrees every way, they cannot shine far enough to reach them.

Fa. Tell me now, why there is but one day and night in the whole year at the poles?

Ch. For the reason which I have just given, the sun must shine beyond the north pole all the time he is vertical to those parts of the earth situated between the equator and the tropic of Cancer; that is, from March the 21st, to September the 20th, during which time there can be no night at the north pole, nor any day at the south pole. The reverse of this may be applied to the southern pole.

Ja. I understand now, that the lengthening and shortening of the days, and the different seasons, are produced by the annual motion of the earth round the sun; the axis of the earth, in all parts of its orbit, being kept parallel to itself. But, if thus parallel to itself, how can it, in all positions, point to the polar star in the heavens?

Fa. Because the diameter of the earth's orbit, A C, is nothing

in comparison with the distance of the earth from the fixed stars. Suppose you draw two parallel lines at the distance of three or four yards from one another, will they not both point to the moon when she is in the horizon?

Ja. Three or four yards cannot be accounted as anything, in comparison with 240 thousand miles, the distance of the moon from us.

Fa. Perhaps, three yards bear a greater proportion to 240 thousand miles than 190 millions of miles bear to our distance from the polar star.

QUESTIONS FOR EXAMINATION.

Explain to me what is intended by fig. 9. — Is the orbit of the earth circular? — How is the sun situated with regard to the earth's orbit? — Are we nearer to the sun in the summer or in the winter? — How is it proved? — Why is the winter colder than the summer? — Which is the hottest time of the year, and why is it so? — Refer to the figure, and tell me the position of the earth in June, and what that occasions. — Do the same with regard to December, March, and September. — Why do the days lengthen and shorten every year from the equator? — Where are there two harvests in a year? — Why is there sometimes no day nor night for a certain number of days or weeks or months within the polar circle? — Why is there but one day and one night in a year at the poles?

CONVERSATION XII.

OF THE EQUATION OF TIME.

Father. You are now, I presume, acquainted with the motions peculiar to the globe on which we live?

Ch. Yes, I think so: it has a rotation on its axis from West to East every 24 hours; by which day and night are produced, and also the apparent diurnal motion of the heavens from East to West.

Ja. The other is its annual revolution in an orbit round the sun, likewise from West to East, at the distance of 95 millions of miles from the sun.

Fa. You understand also in what manner this annual motion of the earth, combined with the inclination of its axis, is the cause of the variety of the seasons; and therefore we will now proceed to investigate another curious subject, viz. the equation of time; and I will endeavour to explain to you the difference between *equal* and *apparent* time.

Ch. Will you tell us what you mean by the words *equal* and *apparent*, as applied to time?

Fa. *Equal* time is measured by a clock, that is supposed to go without any variation, and to measure exactly 24 hours from noon to noon; and *apparent* time is measured by the *apparent* motion of the sun in the heavens, or by a good sun-dial.

Ch. And what do you mean, Papa, by the *equation of time?*

Fa. It is the adjustment of the difference of time, as shown by a well-regulated clock and a true sun-dial: or, astronomically speaking, the difference in mean solar time between the true or apparent right ascension of the sun, and its mean right ascension.

Ja. Upon what does this difference depend?

Fa. It depends, first, upon the inclination of the earth's axis, and, secondly, upon the elliptic form of the earth's orbit; for, as we have already seen, the earth's orbit being an ellipse, its motion is quicker when it is in *perihelion*, or nearest to the sun; and slower when it is in *aphelion*, or furthest from the sun. *Perihelion* is derived from two Greek words, *peri* (περι) "near," and *helios* (ἥλιος) "the sun:" aphelion likewise from *aph* (ἀφ, for ἀπο) "from," and *helios*, "the sun."

Ch. But I do not yet comprehend what the rotation of the earth has to do with the going of a clock or watch.

Fa. The rotation of the earth is the most equable and uniform motion in nature, and is completed in 23 hours, 56 minutes, and 4 seconds. This space of time is called a *sidereal* day; because any meridian on the earth will revolve from a fixed star to that star again in this time. But a *solar* or natural day, which our clocks are intended to measure, is the time which any meridian on the earth will take in revolving from the sun to the sun again; which is about 24 hours, sometimes a little more, but generally less.

Ja. What occasions this difference between the solar and the sidereal day?

Fa. The distance of the fixed stars is so great, that the diameter of the earth's orbit, though it be 190 millions of miles, when compared with it, is but a point; and therefore any meridian on the earth will revolve from a fixed star to

that star again in exactly the same time as if the earth had only a diurnal motion, and remained always in the same part of its orbit. But, with respect to the sun, as the earth advances almost a degree eastward in its orbit, in the same time that it turns eastward round its axis, it must make more than a complete rotation before it can come into the same position again with the sun which it had the day before. In the same way, as when both the hands of a watch or clock set off together at 12 o'clock, the minute-hand must travel more than a whole circle before it will overtake the hour-hand; that is, before they will be in the same relative position again. Thus the sidereal days are shorter than the solar by about four minutes, as is evident from observation.

Ch. Still I do not understand the reason why the clocks and dials do not agree.

Fa. A good clock is intended to measure that equable and uniform time which the rotation of the earth on its axis exhibits; whereas the dial measures time by the *apparent* motion of the sun, which, as we have explained, is subject to variation. Or thus: though the earth's motion on its axis be perfectly uniform, and consequently the rotation of the *equator* (the plane of which is perpendicular to the axis) or of any other circle parallel to it, be likewise equable, yet we measure the length of the natural day by means of the sun, whose *apparent* annual motion is not in the equator, or any of its parallels, but in the ecliptic, which is oblique to it.

Ja. Do you mean by this, that the equator of the earth, in its annual journey, is not always directed towards the centre of the sun?

Fa. I do: twice only in the year, a line drawn from the centre of the sun to that of the earth passes through those points where the equator and ecliptic cross one another: at all other times it passes through some other part of that oblique circle which is represented on the globe by the ecliptic line. Now, when it passes through the equator or the tropics, which are circles parallel to the equator, the sun and clocks go together as far as regards this cause; but at other times they differ, because *equal* portions of the ecliptic pass over the meridian in *unequal* parts of time, on account of its obliquity.

Ch. Can you explain this by a figure?

Fa. It is easily shown by the globe which this figure ♈ N ♎ S may represent: ♈ ♎ will be the equator, ♋ ♎ ♈ the northern half of the ecliptic, and ♈ ♑ ♎ the southern half. Make slight pencil marks *a, b, c, d, e, f, g, h,* all round the *equator* and *ecliptic*, at equal distances (suppose 20 degrees) from each other, beginning at Aries. Now, by turning the globe on its axis, you will

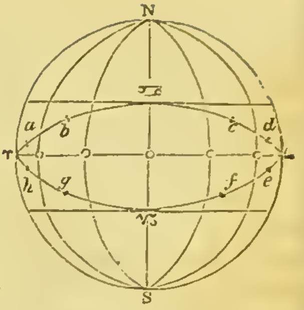


Fig. 10.

perceive that all the marks in the first quadrant of the *ecliptic* (that is, from Aries to Cancer) come *sooner* to the brazen meridian than their corresponding marks on the *equator* :—those from the beginning of Cancer to Libra come *later*:—those from Libra to Capricorn *sooner* :—and those from Capricorn to Aries *later*.

Time, as measured by the sun-dial, is represented by the marks on the *ecliptic;* that measured by a good clock is marked by those on the *equator*.

Ch. Then, while the sun is in the first and third quarters, or, which is the same thing, while the earth is travelling through the second and fourth quarters (that is, from Cancer to Libra, and from Capricorn to Aries) the sun is faster than the clocks; and while it is travelling the other two quarters, it is slower.

Fa. Just so: because, while the earth is travelling through the second and fourth quadrants, equal portions of the ecliptic come *sooner* to the meridian than their corresponding parts of the equator: and during its journey through the first and third quadrants, the equal parts of the ecliptic arrive *later* at the meridian than their corresponding parts of the equator.

Ja. If I rightly understand what you have been saying, the dial and clocks ought to agree at the equinoxes; that is, on the 20th of March, and the 23d of September; but if I refer to the Ephemeris, I find that for that year on the former day the clock is more than seven minutes before the sun; and on the latter day it is almost seven minutes behind the sun.

Fa. If this difference between time measured by the sun-dial and clock depended only on the inclination of the earth's axis to the plane of its orbit, the clock and dial ought to be together at the equinoxes, and also on the 21st of June and

the 21st of December; that is, at the summer and winter solstices; because, on those days, the *apparent* revolution of the sun is parallel to the equator. But I told you that there was another cause why this difference subsisted.

Ch. You did: and that was the elliptic form of the earth's orbit.

Fa. If the earth's motion in its orbit were uniform, which it would be if the orbit were circular, then the whole difference between *equal* time, as shown by the clock, and *apparent* time, as shown by the sun, would arise from the inclination of the earth's axis. But this is not the case; for the earth travels, when it is nearest the sun, that is, in the winter, more than a degree in 24 hours; and when it is furthest from the sun, that is, in summer, less than a degree in the same time: consequently, from this cause the natural day would be of the greatest length when the earth was nearest the sun; for it must continue turning the longest time after an entire rotation, in order to bring the meridian of any place to the sun again; and the shortest day would be when the earth moves the slowest in her orbit. Now, these inequalities, combined with those arising from the inclination of the earth's axis, make up that difference which is shown by the equation table, found in the Ephemeris, between good clocks and true sun-dials. We may add, in conclusion, that the equation of time is at its maximum about the beginning of November, when it amounts to about 16 minutes 16 seconds, at which quantity the clock is faster than the dial.

QUESTIONS FOR EXAMINATION.

Enumerate the motions of the earth. — What is meant by equal time; and what, by apparent time? — What is understood by the equation of time? — Upon what does the difference between a well-regulated clock and a true sun-dial depend? — How has the rotation of the earth anything in common with the motion of a watch? — What occasions the difference between the solar and sidereal day? — What time do clocks and watches measure? — What time is that which is measured on the sun-dial? — How often is the equator of the earth directed towards the centre of the sun? — How often do the clocks and sun-dials agree? — Explain this by means of fig. 11. — When is the sun faster than the clocks; and when, slower? — What is the cause of this difference? — What difference does the elliptic form of the earth's orbit occasion? — Does the earth travel faster in summer or in winter?

CONVERSATION XIII.

OF LEAP-YEAR.

James. Before we quit the subject of time, will you give us some account of what is called, in our Almanacs, "LEAP-YEAR"?

Fa. I will. The length of our year is measured, as you are aware, by the time which the earth takes in performing her journey round the sun, in the same manner as the length of the day is measured by its rotation on its axis. Now, to compute the exact time taken by the earth in its annual journey, was a work of considerable difficulty. Julius Cæsar was the first person who seems to have attained to any accuracy on this subject.

Ch. Do you mean the Julius Cæsar who invaded Great Britain?

Fa. The same. He was not less celebrated as a man of science than as a general.

This renowned commander, who was well acquainted with the learning of the Egyptians, in the year 45 B.C. determined the length of the year to be 365 days and six hours; which made it six hours longer than the Egyptian year. Now, in order to allow for the odd six hours in each year, he introduced an additional day every fourth year, which accordingly consists of 366 days; and is called *Leap*-Year, while the other three have only 365 days each. From him it was denominated the *Julian* year.

Ja. It is also called *Bissextile* in the Almanacs. What does that mean?

Fa. The Romans inserted the intercalary day between the 23d and 24th of February: and because the 23d of February in their calendar, was called *sexto calendas Martii* (the sixth of the calends of March), the intercalated day was called BIS *sexto calendas Martii,* the SECOND sixth of the calends of March, from being reckoned twice; and hence the year of intercalation had the appellation of *Bissextile.* This day was chosen at Rome, on account of the expulsion of Tarquin from the throne, which happened on the 23rd of February. We

also introduce, in Leap-Year, a new day in the same month; namely, the 29th.

Ch. Is there any rule for distinguishing Leap-Year from any other?

Fa. Yes. It is known by dividing the date of the year by 4. If there be no remainder, it is Leap-Year. Thus, 1846, divided by 4, leaves a remainder of 2, showing that it is the second year after Leap-Year. These two lines contain the rule:

The year divide by 4; what 's left will be,
If Leap-Year, 0; if past, 1, 2, or 3.

Ja. The year, however, does not consist of 365 days and 6 hours, but of 365 days, 5 hours, 48 minutes, and 51·6 seconds.* Will not this occasion some error?

Fa. It will: and by subtracting the latter number from the former, you will find that the error amounts to 11 minutes and 11 seconds every year, or to a whole day in about 130 years: notwithstanding this, the Julian year continued to be in general use till 1582, when Pope Gregory XIII. undertook to rectify the error, which, at that time, amounted to ten days, the vernal equinox falling on the 11th instead of the 21st of March. He accordingly directed the ten days between the 4th and 15th of October in that year to be suppressed, so that the 5th day of that month was called the 15th. This alteration took place through the greater part of Europe in that year, and in most other states in 1710; and the computation was afterwards called the Gregorian or *New Style*. In this country, the method of reckoning, according to the New Style, was not admitted into our calendars till the year 1752, when the error amounted to nearly 11 days, which were taken from the month of September, by calling the 3d of that month the 14th. In Russia and Greece, however, the *Old* or *Julian* style still prevails: the distinctive mark is O.S. or N.S.

Ch. By what means will this accuracy be maintained?

Fa. The error amounts to one whole day in about 130 years, or three days in 400 years; and it was settled by an act of parliament, that the year 1800 and the year 1900, which are, according to the rule just given, Leap-years, shall be computed as common years of only 365 days in each; but that the

* See Conversation IX.

year 2000 shall be *Leap-Year;* and that every fourth hundredth year afterwards should also be reckoned as Leap-Years, so that in 2100, 2200, 2300 the interealary day is suppressed, but not so in 2400. By adhering to this method, the present mode of reckoning will not deviate a single day from true time for 5000 years.

By the same aet of parliament, the beginning of the year was changed by law from the 25th of March to the 1st of January. So that the succeeding months of January, February, and March, up to the 24th day, which would, by the Old Style, have been reckoned part of the year 1752, were accounted as the three first months of the year 1753. From this variation in the computation of time, we may easily account for the difference of many dates concerning historical facts and biographical notices.

Ch. Why, Papa, has this the name of *Leap-Year?*

Fa. The appellation is derived probably from the *leap* or start occasioned by the insertion of the intercalary day. The term *intercalary* is from the Latin *inter* " between," and *calo* " to eall."

QUESTIONS FOR EXAMINATION

Who fixed the length of the year to 365 days and a quarter? — What is Leap-year? — What is the meaning of the word *bissextile?* — What new day is admitted in Leap-year? — What is the rule for finding whether the present year is or is not Leap-year? — Does the year consist of 365 days 6 hours exactly? — What is the error, and in how long will it amount to a day? — Who reformed the Julian year, and when did the alteration take place in the greater part of Europe? — When was the "NEW STYLE" adopted in England? — Is any method provided to maintain accurate time? — Did the legal year always begin on the 1st of January in this country?

CONVERSATION XIV.

OF THE MOON.

Father. You are now acquainted with the reasons for the division of time into days and years.

Ch. These divisions have their foundation in nature: the *former* depending upon the rotation of the earth on its axis; the *latter* upon its revolution in an elliptic orbit about the sun, as a eentre of motion.

Ja. Is there any natural reason for the division of years into weeks, or of days into hours, minutes, and seconds?

Fa. The origin of the division of time into weeks has by the generality of authors been assigned to the Egyptians; Dio Cassius affirms that they distinguished this period of seven days by the names of the seven planets then known, beginning in the order of their distance from the earth, and from which origin their present names are derived;* but it appears rather that this must have been a Divine appointment descending down to us from the creation of the world; the other division was invented entirely for the convenience of mankind, and is accordingly different in different countries. There is, however, another division of time marked out by nature.

Ch. What is that, Papa?

Fa. The length of the *month:* not indeed that month which consists of four weeks, nor that by which the year is divided into 12 parts. These are both arbitrary; but by a month is meant the time which the moon takes in performing her journey round the earth.

Ja. How many days does the moon require for this purpose?

Fa. Your question involves two answers: for if you refer to the time in which the moon revolves from one point of the heavens to the same point again, it consists of 27 days, 7 hours, and 43 minutes; this is called its *tropical* revolution and forms the *periodical* month: but if you refer to the time passed from the new moon to new moon again, that is, from conjunction to conjunction, the month consists of 29 days 12 hours and 44 minutes; this is called the *synodical* month.

Ch. Pray explain the reason of this difference.

Fa. It is occasioned by the earth's annual motion in its orbit. Let us refer to our watch for illustration. The two hands are together at twelve o'clock. Now, when the

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* The English names are derived from the Saxon; thus—

English Names.	*Saxon Names.*	*Presided over by*	*Latin Names.*
Saturday............	Saterne's Day......	Saturn................	Dies Saturni.
Sunday..............	Sun's day............	The Sun.............	Dies Solis.
Monday..............	Moon's day.........	The Moon...........	Dies Lunæ.
Tuesday.............	Tuesco's day	Mars..................	Dies Martis.
Wednesday.........	Woden's day	Mercury	Dies Mercurii.
Thursday...........	Thor's day	Jupiter	Dies Jovis.
Friday...............	Friga's day	Venus	Dies Veneris.

minute-hand has made a eomplete revolution, are they together again?

Ja. No: for the hour-hand is advaneed the twelfth part of its revolution, and the other must travel five minutes more than the hour to overtake it.

Fa. And something more; for the hour-hand does not wait at the figure 1 till the other comes up: and therefore they will not be together 'till between 5 and 6 minutes after *one*.

Now apply this to the earth and moon. Suppose s to be the sun; T the earth in a part of its orbit Q L; and E to be the position of the moon. If the earth had no motion, the moon would move round its orbit E H C, into the position E again, in 27 days, 7 hours, 43 minutes; but, while the moon is describing her journey, the earth has passed through nearly a twelfth part of its orbit, whieh the moon must also describe before the two bodies eome again into the same position they before held with respect to the sun. This takes up so much more time as to make her synodieal month equal to 29 days, 12 hours and 44 minutes. Henee the foundation of the division of time into months.

Fig. 11.

There are also three other revolutions of the moon; the *Sidereal*, whieh is the time she takes in proeeeding from a fixed star till she returns to it again: and which differs from the periodie in only 7 seeonds—the *Anomalistic*, which is the interval from perigee to perigee, or from the nearest point of her orbit to the earth, to the same point again, whieh is longer than the tropical or periodie, yet shorter than the synodie; and the *Nodical*, which is the interval from node to node, and whieh is mueh shorter than all the others.* The

* To be more accurate—

			Days.
The *Synodic* Revolution	comprises		29·53059.
Sidereal	"	"	27·32166.
Tropical	"	"	27·32158.
Anomalistic	"	"	27·55460
Nodical	"	"	27·21222.

term *synodic* is from the Greek *sŭn* (συν) "together," and *odos* (οδος) "a pathway;" and is the same as a *lunar* month or *lunation*. *Anomalistic* is from *anomalos* (ἀνωμαλος) "unequal or irregular." *Perigee* is from *peri* (περι) "near," and *gē* (γη) "the earth."

We will now proceed to describe some other particulars relating to the moon, as a body depending, like the earth, on the sun for her light and heat.

Ch. Does the moon shine with a borrowed light only?

Fa. Certainly: for otherwise, if she were a luminous body, like the sun, she would always shine with a full orb as the sun does. Do you remember her diameter and distance from the earth?

Ja. Her diameter is about 2160 miles. And I think that she is at the distance of about 237,000 miles from the earth.

Fa. The sun S, (fig. 11) always enlightens one half of the moon E; and it is according to her different positions in her orbit with respect to the earth, we perceive either her whole enlightened hemisphere, or a part of it, or none at all; for only those parts of the enlightened moon are visible, at T, which are inclosed *within* the orbit.

Ja. Then, when the moon is at E, no part of its enlightened side is visible to the earth.

Fa. Surely not: it is then *new* moon, or *change*, for it is usual to call it a New Moon the first day it is visible to the earth, which is not till the second day after the change. And the moon being then in a line between the sun and earth, they are said to be in *conjunction*.

Ch. And at A, all the illuminated hemisphere is turned to the earth.

Fa. This is called *full* moon; and the earth being then between the sun and moon, they are said to be in *opposition*. The enlightened parts of the little figures on the outside of the orbit represent the appearances of the moon as seen by a spectator on the earth.

Ja. Is the little figure, then, opposite E wholly dark, to show that the moon is invisible at change?

Fa. It is: and when it is at F, a small part of the illuminated hemisphere is visible; and therefore, to a spectator at T, it appears *horned;* at G, one half of the enlightened hemi-

sphere is visible, and it is said to be in *quadrature:* at H, three-fourths of the enlightened part is visible to the earth, and it is then said to be *gibbous:* and at A, the whole enlightened face of the moon is turned to the earth, and it is said to be *full.* The same may be said of the rest; but I will add further, that the horns of the moon, before conjunction or new moon, are turned to the *East:* but after conjunction they are turned to the West.

Ch. I see the figure is intended to show that the moon's orbit is elliptical. Does she also turn upon her axis?

Fa. She does; and she takes the same time exactly for her diurnal rotation as in completing her sidereal revolution about the earth. Consequently, though every part of the moon is successively presented to the sun, yet the same hemisphere is always turned to the earth. This is known by observation with good telescopes: the different phases of the moon may be prettily and familiarly illustrated by taking a small globe, with a string fastened to it, and swing it round the head. The head will represent the earth, and the globe will represent the moon revolving round the earth.

Now place a lamp on a stand as high as the head, in the centre of the room, to represent the sun. And as the moon revolves round us, we must suppose that no part of it is visible, except so much of its surface as is illuminated by the lamp. It is then evident, that when the moon comes between us and the sun, or in conjunction with it, the brightened part of the moon will be wholly from us, and will disappear. This represents what is called the "CHANGE OF THE MOON."

As the moon goes forward, the illuminated side begins to come in sight; this represents the "NEW MOON."

When the moon has advanced one quarter of the way round from the sun, we see one half of the illuminated side; this represents the moon "*Half Full,*" and what is called her "FIRST QUARTER."

As the moon goes on in her orbit the enlightened part comes more and more into view, till it is exactly on the opposite side of us from the sun, when the whole of the enlightened part will be towards us: this represents "FULL MOON."

As the moon proceeds from *Opposition* through the other half of her orbit, the enlightened side will be turned more and

more from us, till it comes again into *conjunction*, which represents the "CHANGE," as before.

When the moon is in this position, and in a direct line between the eye and the sun, the latter is in "ECLIPSE." When the moon is in *opposition*, and the earth is directly between her and the sun, the MOON is in "ECLIPSE."

Ja. Is the length of a day and night in the moon equal to more than twenty-nine days and a half of ours?

Fa. Yes: and therefore, as the length of her year, which is measured by her journey round the sun, is equal to that of ours, she can have but about twelve days and one third in a year. Another remarkable circumstance relating to the moon is, that the hemisphere next the earth is never in darkness; for, in the position E, when it is turned from the sun, it is illuminated by light reflected from the earth, in the same manner as we are enlightened by the light reflected from the moon. But the other hemisphere of the moon has a fortnight's light and darkness by turns.

Ch. Can the earth, then, be considered as a satellite to the moon?

Fa. It would, perhaps, be inaccurate to denominate the larger body a satellite to the smaller; but, with regard to affording reflected light, the earth is to the moon what the moon is to the earth, and subject to the same changes of horned, gibbous, full, &c.

Ch. But it must appear much larger than the moon.

Fa. The earth will appear to the inhabitants of the moon about 13 times as large as the moon appears to us. When it is *new moon* to us, it is, if I may use the expression, *full earth* to them, and *vice versa.*

Ch. What is meant by the *cycle* of the moon, Papa?

Fa. The word *cycle* from the Greek *cuclos*, (κυκλος) "a circle," means the revolution of a certain period of time, which at its close recommences and proceeds as before, and thus perpetually: there is the *cycle* of the sun, and the *cycle* of the moon. This period, with respect to the moon, comprises 19 solar years, after which the new and full moons fall on the same days, year after year, as they did the 19 years before. It was invented by Meton, a celebrated astronomer of Athens, hence it has been also called the *Metonic* cycle.

Ja. Is the moon, then, inhabited, as well as the earth?

Fa. Though we cannot demonstrate this fact, yet there are many reasons to induce us to believe it: for the moon, though a secondary planet, is yet of considerable size;—and when viewed through a good telescope, its surface appears diversified, like that of the earth, with mountains and valleys. The former have been observed by Dr. Herschel, and some of them he has estimated to be a mile and three quarters in perpendicular height. The situation of the moon, with respect to the sun, is much like that of the earth; and, by a rotation on her axis, and a small inclination of that axis to the plane of her orbit, she enjoys, though not a considerable, yet an agreeable variety of day and night and of seasons. To the moon, our globe must appear a valuable satellite, undergoing the same changes of illumination as the moon does to the earth. The sun and stars rise and set there the same as they do here; and heavy bodies will fall by the attraction of gravitation on the moon as they do on the earth. Hence we are led to conclude that, like the earth, the moon also is inhabited Dr. Herschel discovered, some years ago, three volcanoes burning in the moon; the bright spot, named Tycho, in her south-east quarter, he considered to be a volcanic crater 50 miles in diameter, and 16,000 feet deep, surrounded by broad terraces within, and with a central mountain about 5000 feet high: there are also large regions perfectly level, but no large seas or any tracts of water have been yet observed there; nor is the existence of a lunar atmosphere of a density sufficient to refract rays of light a certainty. Therefore her inhabitants must materially differ in their constitution from those who inhabit the earth; that of all the celestial bodies, next the sun, the moon to us is the most interesting. That this planet is inhabited by sensible and intelligent beings, there is every reason to conclude, from a consideration of the varied features which her surface presents; and of the general beneficence of the Creator, who appears to have left no portion of His material creation without *animated existences*, which we daily witness in everything around us: yet to our senses her surface presents no appearance of vegetation, or that variation indicative of a change of seasons: in fact all appears solid, desolate, and unfit for the support of life, animal or vegetable.

QUESTIONS FOR EXAMINATION.

Upon what does the division of time into days and years depend? — What other division of time is marked out by nature? — What do you mean by a month? — What is the difference between a periodical and synodical month? — What is the reason of this difference? — Explain this by fig. 11. — By what light does the moon shine? — What is the length of the moon's diameter? — Explain by the figure the changes of the moon. — Does the moon turn about on her axis, and in what time? — How do you illustrate the different phases of the moon? — When is the "new moon?" — When full? change? eclipse? — How many days are there in the moon's year? — Is there any other remarkable circumstance relating to the moon? — Can the earth be considered as a satellite to the moon? — How large will the earth appear to the inhabitants of the moon? — What reasons are there to prove that the moon is inhabited?

CONVERSATION XV.

OF ECLIPSES.

Charles. Will you now, Papa, explain to us the nature and cause of eclipses.

Fa. I will, with great pleasure. You must observe, then, that eclipses depend upon this simple principle: that all opaque or dark bodies, when exposed to any light, whether to the light of the sun, or any other body, cast a shadow behind them in an opposite direction.

Ja. The earth, being a body of this kind, must cast a very large shadow on the side opposite to the sun.

Fa. It does: and an eclipse of the moon happens when the earth, T, passes between the sun, S, and the moon, M; and it is occasioned by the earth's shadow being cast on the moon.

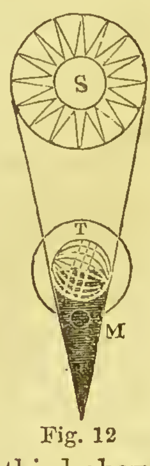

Fig. 12

Ch. When does this happen?

Fa. It is only when the moon is at full, or in *opposition*, that it comes within the shadow of the earth.

Ja. Eclipses of the moon, however, do not happen every time it is full. What is the reason of this?

Fa. Because the orbit of the moon does not coincide with the plane of the earth's orbit; but one half of it is elevated about five degrees and a third above it, and the other half is as much below it: therefore, unless

the full moon happen to occur in or near one of the nodes, that is, in or near the points in which the two orbits intersect each other, she will pass above, or below the shadow of the earth; in which case there can be no eclipse.

Ch. What is the greatest distance from the node at which an eclipse of the moon can happen?

Fa. There may be an eclipse, if the moon, at the time when she is full, is within 12 degrees from the node; and there *must* be if she is within 7 degrees; and the eclipse will be *partial*, or *total*, according as a part, or the whole disk, or face, of the moon falls within the earth's shadow. If the eclipse happen exactly when the moon is full in the node, it is called a central eclipse; and the centres of the sun, earth, and moon, are then in one straight line.

Ja. I suppose the duration of the eclipse lasts all the time that the moon is passing through the shadow.

Fa. It does: and you may observe that the shadow is considerably wider than the moon's diameter; and as the moon takes about an hour to pass over a space equal to her diameter, so therefore an eclipse of the moon lasts sometimes upwards of two hours. The shadow also, you perceive, is of a conical shape, and consequently, as the moon's orbit is an ellipse and not a circle, the moon will, at different times, be eclipsed when she is at different distances from the earth.

Ch. And in proportion as the moon is nearer to or farther from the earth, the eclipse will be of a greater or less duration; for the shadow, being conical, becomes less and less, as the distance from the body by which it is cast is greater.

Fa. It is by knowing exactly at what distance the moon is from the earth, and of course the width of the earth's shadow at that distance, that all eclipses are calculated, with the greatest accuracy, for many years before they happen. Now, it is found that in all eclipses, the shadow of the earth is conical, which is a proof that the body by which it is projected is of a spherical form; for no other sort of figure would, in all *positions*, cast a conical shadow. This is mentioned as another evidence that the earth is a spherical body. It is moreover found that the earth's shadow extends 216 times the length of its radius, and consequently far beyond the orbit of the moon; and the apparent diameter of the conical shadow at the mean distance of the moon is about 1° 23′, so that if

the moon happens to be in the plane of the ecliptic, when full, the whole lunar disk will be involved in the earth's shadow.

Ja. It seems to me to prove another thing; viz. that the sun must be a larger body than the earth.

Fig. 13.

Fig. 14.

Fa. Your conclusion is just: for if the two bodies were equal to one another (fig. 13) the shadow would be cylindrical; and if the earth were the larger body (fig. 14) its shadow would be of the figure of a cone, which had lost its vertex, and the farther it were extended the larger would it become. In either case it would run out to an infinite space, and accordingly must sometimes involve in it the other planets; which is contrary to fact. Therefore, since the earth is neither larger than, nor equal to, the sun, it must be the lesser body.—We will now proceed to the eclipses of the sun.

Ch. How are these occasioned?

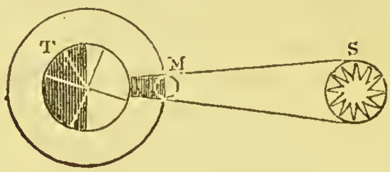

Fig. 15.

Fa. An eclipse of the sun happens when the moon, M, passing between the sun, S, and the earth, T, intercepts the sun's light.

Ja. The sun, then, can be eclipsed only at the new moon.

Fa. Certainly: for it is only when the moon is in *conjunction*, that it can pass directly between the sun and earth.

Ch. It is only when the moon, at her conjunction, is near one of its nodes, and the centres of the sun, moon, and earth are in one straight line, that there can be an eclipse of the sun?

Fa. An eclipse of the sun depends upon this circumstance: for unless the moon is in, or near, one of its nodes, she cannot appear in the same plane with the sun, or seem to pass over his disk. In every other part of the orbit, she will appear above or below the sun. If the moon be *in* one of the nodes, she will, in most cases, cover the whole disk of the sun, and produce a *total* eclipse: if she be anywhere within about 16 degrees of a node, a *partial* eclipse will be produced.

The sun's diameter is supposed to be divided into 12 equal parts, called *digits;* and in every partial eclipse, so many of

these parts of the sun's diameter as the moon covers are said to be eclipsed; and this is formed not by the perfect conical shadow in whieh the eclipse would be total, but by the *penumbra;* from the Latin *pene* "almost" and *umbra* "a shadow."

Ja. I have heard of *annular* eelipses. What are they, Papa?

Fa. When a ring of light appears round the edge of the moon during an eclipse of the sun, it is said to be annular, from the Latin word *annulus,* "a little ring:" these kinds of eclipses are occasioned by the moon being at her greatest distance from the earth at the time of an eclipse; because, in that situation, the vertex or tip of the cone of the moon's shadow does not reach the surface of the earth: but when the moon's shadow extends beyond the earth's surface, its intersection with the surface marks out a circular spot, within whieh no part of the sun's disk is visible, and there is a total eclipse.

Ch. How long can an eelipse of the sun last?

Fa. A total eclipse of the sun is a very curious and uncommon spectacle; and total darkness cannot last more than three or four minutes. Of one that was observed in Portugal, about 200 years ago, it is said that the darkness was greater than that of night; that stars of the first magnitude were visible, and that the birds were so terrified, that they fell to the ground.

Ja. Was this visible only at Portugal?

Fa. There is no doubt but it was witnessed in countries adjacent. The moon, being a body much smaller than the earth, and having also a conical shadow, can with that shadow only cover a small part of the earth; whereas an eclipse of the moon may be seen by all those that are on that hemisphere which is turned towards it. (Fig. 15 and 12.) You will also observe that an eclipse of the sun may be *total* to the inhabitants near the middle of the earth's disk, and *annular* to those in places near the edges of the disk; for, in the former case, the moon's shadow will reach the earth; and in the latter, on account of the earth's sphericity, it will not.

Ch. Have not eclipses been esteemed as omens presaging some direful calamity.

Fa. Yes; until the causes of these appearances were discovered, they struck with terror and dismay the generality of

the people, then plunged into the grossest ignorance and barbarism: but they were taken advantage of by the priests of pagan times, whose superior learning led them to comprehend in some degree their causes, to establish their superstitions and idolatry, and to uphold their pre-eminence and power.

QUESTIONS FOR EXAMINATION.

Upon what do eclipses depend? — When does an eclipse of the moon happen? — What is the reason that eclipses of the moon do not always happen when the moon is full? — In what ease will there be no eclipse at the time of full moon? — What is a central eclipse? — How long does an eclipse of the moon last? — Of what shape is the shadow of the earth? — What things are necessary to be known in calculating an eclipse of the moon? — How is it proved that the sun is larger than the earth? — When does an eclipse of the sun happen? — Upon what does an eclipse of the sun depend? — When will there be a *total* and when a *partial* eclipse? — What is meant by an *annular* eclipse? — How long can a total eclipse of the sun last? — Are total eclipses common? — Explain by figs. 15 and 12 how an eclipse of the sun may be *total* to the inhabitants near the middle of the earth's disk, and annular to some others.

CONVERSATION XVI

OF THE TIDES.

Father. We will proceed to the consideration of the *Tides*, or the flowing and ebbing of the ocean.

Ja. Is this subject connected with astronomy?

Fa. It is: inasmuch as the tides are occasioned by the attraction of the sun and moon upon the waters; particularly by that of the latter. You will readily conceive that the tides are dependent upon some known and determinate laws; because, if you turn to the Ephemeris, or indeed to almost any Almanac, you will see laid down the exact time of high water at London-bridge and at certain of our sea-ports for every day in the year.

Ch. I have frequently wondered how this could be known with such a degree of accuracy: indeed, there is not a waterman that plies at the river but can readily tell when it will be high water.

Fa. The generality of the watermen are probably ignorant of the cause by which the waters flow and ebb; but by experience they know that the time of high water differs, on each day, about three quarters of an hour, or a little more or less;

and therefore, if it be high water to-day at six o'clock, they will, at a guess, tell you, that to-morrow the tide will not be up till a quarter before seven.

Ja. Will you explain the cause?

Fa. I will, and it shall be my endeavour to do this in an easy and concise manner, without fatiguing your memory with too great a variety of particulars. You must bear in mind, then, that the tides are occasioned by the attraction of the sun and moon upon the waters of the earth. Perhaps a figure may be of some assistance to you. Let *apln* be supposed the earth, *c* its centre: let the dotted circle represent a mass of water covering the earth: let *m* be the moon in its orbit, and *s* the sun.

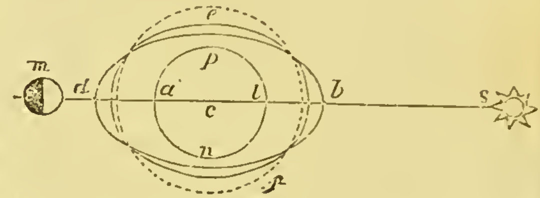

Fig. 16.

Since the force of gravity or attraction diminishes as the squares of the distances increase,* the waters on the side *a* are more attracted by the moon, *m*, than the central parts at *c;* and the central parts are more attracted than the waters at *l;* consequently the waters at *l* will recede from thence. Therefore, while the moon is in the situation *m*, the waters will rise towards *a* and *b* on the opposite sides of the earth.

Fa. You mean that the waters will rise at *a* by the immediate attraction of the moon *m*, and will rise at *b* by the centre *c*, receding and leaving them more elevated there.

Fa. Just so. It is evident that, the quantity of water being the same, a rise cannot take place at *a* and *b*, without the parts at *p* and *n* being at the same time depressed.

Ja. In this situation the water may be considered as partaking of an oval form.

Fa. If the earth and moon were without motion, and the earth entirely covered with water, the attraction of the moon would raise it up in a heap in that part of the ocean to which the moon is vertical, and there it would always continue: but by the rotation of the earth on its axis, each part of its surface to which the moon is vertical is presented twice a day to the action of the moon; and thus are produced two floods and two ebbs.

* See p. 27.

Ch. How twice a day?

Fa. In the position of the earth and moon, as it is in our figure, the waters are raised at *a* by the direct attraction of the moon, and a tide is accordingly produced : but when by the earth's rotation, *a* comes, 12 hours afterwards, into the position *l*, another tide is occasioned by the receding of the waters there from the centre.

Ja. You have told us that the tides are produced in those parts of the earth to which the moon is vertical; but this effect is not confined to those parts.

Fa. It is not: but there the attraction of the moon has the greatest effect. In all other parts her force is weaker, because it acts in a more oblique direction.

Ch. Are there two tides in every 24 hours?

Fa. If the moon were stationary, this would be the case; but because that body is also proceeding every day about 13 degrees from west to east in her orbit, the earth must make more than one revolution on its axis before the same meridian comes in conjunction with the moon; and hence two tides take place in about 24 hours and 50 minutes.

Ja. But the tides rise higher at some seasons than at others. How do you account for that?

Fa. The moon goes round the earth in an elliptical orbit, and therefore she approaches nearer to the earth in some parts of her orbit than in others. When she is nearest, the attraction is the strongest, and consequently the tides are highest: and when she is farthest from the earth her attraction is the least, and the tides therefore the lowest.

Ch. You said that the sun's attraction occasioned tides, as well as that of the moon.

Fa. It does: but, owing to the immense distance of the sun from the earth, it produces but a small effect in comparison with the moon's attraction. Sir Isaac Newton computed that the force of the moon raised the waters in the ocean 10 feet, whereas that of the sun raised it only two feet. When the attraction of both sun and moon acts in the same direction (that is, at new and full moon) the combined forces of both raise the tide 12 feet: but when the moon is in her quarters, the attraction of one of these bodies raises the water where that of the other depresses it; and therefore, the smaller force of the sun must be subtracted from that of the moon ; conse-

quently, the tides will not be more than 8 feet. The highest tides are called *spring*-tides, and the lowest are denominated *neap*-tides: the greatest height the tide has been known to rise is about 100 feet.

Ja. I understand that, in the former case, the height to which the tides are raised must be calculated by *adding* together the attractions of the sun and moon; and in the latter, it must be estimated by the *difference* of these attractions.

Fa. You are right. When the sun and moon are both vertical to the equator of the earth, and the moon at her least distance from the earth, then the tides are highest.

Ch. Then the highest tides happen at the Equinoxes?

Fa. Strictly speaking, these tides do not happen till some little time after; because in this, as in other cases, the actions do not produce the greatest effect when they are at the strongest, but some time afterwards: thus the hottest part of the day is not when the sun is in the meridian, but at two or three o'clock in the afternoon. Another circumstance must be taken into consideration: the sun being nearer to the earth in winter than in summer, it is of course nearer to it in February and October, than in March and September; and therefore, all these reasons being put together, it will be found that the greatest tides happen a little before the vernal, and some time after the autumnal, Equinoxes.

Ja. To whom are we indebted for an insight into the nature of tides?

Fa. Although the cause of the tides was known to the ancients, yet it was first rationally explained by Kepler, and afterwards more fully by Sir Isaac Newton, who solved, in his Principia, many difficulties on the subject, which before were thought inexplicable; and explained many of the principles upon which the phenomena of the tides depend, which have subsequently been improved upon by Maclaurin, Laplace, Dr. Young, and more recently by Dr. Whewell, of Cambridge.

Ch. Are the tides of equal height in every locality?

Fa. By no means; the height is affected by various circumstances; in deep gradually contracting indentations of the shore, the tide rises most considerably; in the Bristol Channel, in the bay of Fundy, and in that of St. Malo, the tide has been known to rise 100 feet. At Chepstow, opposite the Bristol

Channel, the difference between high and low water mark averages 60 feet; at Bristol, the average is 33 feet; at the London-docks, 22 feet; at Liverpool, 15·5 feet; at Portsmouth and Plymouth, 12·5 feet; in the middle of the Pacific, and on certain parts of the south-east coast of Ireland, the average is but 2 or 3 feet; while in the Mediterranean and in the Black Sea the tides are scarcely to be discerned. The wind, and atmospheric pressure also materially affect the flowing of the tides. Sir J. Lubbock affirms, that at Gainsborough, 25 miles up the Trent, during the violent hurricane of January 8, 1839, there was *no tide* at all, a circumstance unknown before; and in other places under the influence of high and continuous winds, the tides have wonderfully *ebbed*, or as wonderfully *flowed*. In regard to atmospheric pressure, at Brest the height of high-water varies inversely as the height of the barometer: at Liverpool, a fall of 1-10th in the barometer corresponds to a rise in the Mersey of about an inch: and a like fall at the London-docks corresponds to a rise of 7-10ths in the Thames: and so of other places, a low barometer effecting high tides, and a high barometer low tides.

QUESTIONS FOR EXAMINATION.

Upon what do the tides depend? — What is the daily difference in time in high water? — Explain to me by fig. 16 how the tides are occasioned. — How often are there tides? — Why are there not two tides in 24 hours? — Is there any difference in the heights to which the tides rise with regard to the seasons of the year? — In what position are the earth and moon when the tides are highest? — Are there high tides in the Mediterranean? — Where do they rise 33 feet high? — Has the sun or the moon the greater effect in producing tides, and why? — What are the highest, and what the lowest tides called? — When are the tides highest? — Do the highest tides happen at the equinoxes?

CONVERSATION XVII.

OF THE HARVEST-MOON.

Father. From what we said yesterday you will easily understand the reason why the moon rises about three-quarters of an hour, or rather 52 minutes later every day than on the one preceding.

Ch. It is owing to the daily progress which the moon is

making in her orbit; on which account any meridian on the earth must make more than one complete rotation on its axis before it comes again into the same situation with respect to the moon, that it had before. And you told us that this occasioned a difference of about 52 minutes.

Fa. At the equator this is generally the difference of time between the rising of the moon on one day and that preceding. But in places of considerable latitude, as that in which we live, there is a remarkable difference about the time of harvest, when, at the season of full moon, she rises, for several nights together, only about 15 or 20 minutes later on the one day than on that immediately preceding. By thus succeeding the sun before the twilight is ended, the moon prolongs the light, to the great benefit of those who are engaged in gathering in the fruits of the earth: hence the full moon at this season is called the harvest-moon. It is believed that this was observed by persons engaged in agriculture at a much earlier period than it has been noticed by astronomers: the former ascribed it to the goodness of the Deity; not doubting that he had so ordered it purposely for their advantage.

Ja. But the people at the equator do not enjoy this advantage.

Fa. Nor is it necessary that they should; for, in those parts of the earth, the seasons vary but little, and the weather changes but seldom, and at stated times; to them, then, moon-light is not wanting for gathering in the fruits of the earth.

Ch. Can you explain how it happens that the moon, at this season of the year, rises one day after another with so small a difference in regard to time?

Fa. With the assistance of a globe I could at once clear away the difficulty. But I will endeavour to give you a general idea of the subject without that aid. That the moon loses more time in her rising when she is in one part of her orbit, and less time in another, is occasioned by her orbit being sometimes more oblique to the horizon than at others.

Ja. But the moon's path is not marked on the globe.

Fa. It is not. You may, however, consider it, without much error, as coinciding with the ecliptic: and to the latitude of London, as much of the ecliptic rises about *Pisces* and *Aries*, in two hours, as the moon goes through in six days.

Therefore, while the moon is in these signs, she differs but two hours in rising, for six days together; that is, on the average of about 15 or 20 minutes later every day than on that preceding.

Ch. Is the moon in those signs at the time of harvest?

Fa. In August and September you know that the sun appears in Virgo and Libra, and of course, when the moon is *full*, she must be in the opposite signs: viz., *Pisces* and *Aries.*

Ja. Then there are two periods of full moons that afford us this advantage?

Fa. There are: the one when the sun is in Virgo, which is called the *harvest* moon; the other, when the sun is in Libra, and which, comparatively speaking, is less important, is called the *hunter's* moon. You must know, however, that when the moon is in Virgo and Libra, she then rises with the greatest difference of time; viz. an hour and quarter later every day than the former.

Ch. Will you explain, Papa, how it is that the people at the equator have no harvest-moon?

Fa. At the equator, the north and south poles lie in the horizon; and therefore the ecliptic makes the same angle southward with the horizon, when Aries rises, as it does northward when Libra rises; but as the harvest-moon depends upon the different angles at which different parts of the ecliptic rise, it is evident there can be no harvest-moon at the equator.

The farther any place is from the equator, if it be not beyond the polar circles, the angle which the ecliptic makes with the horizon, when Pisces and Aries rise, gradually diminishes; and therefore, when the moon is in these signs, she rises with a nearly proportionable difference later every day than on the former; and this is more remarkable abont the time of full moon.

Ja. Why have you excepted the space on the globe beyond the polar circles?

Fa. At the polar circles, when the sun touches the summer tropic, he continues 24 hours above the horizon, and 24 hours below it when he touches the winter tropic. For the same reason the full moon neither rises in the summer, when she is not wanted, nor sets in the winter when her presence is so necessary. These are the only two full moons which

happen about the tropics: for all the others rise and set. In summer, the full moons are low, and their stay above the horizon short: in winter they are high, and their stay longer above the horizon. A wonderful display is here presented to us of the divine wisdom and goodness, in apportioning the quantity of light to the various necessities of the inhabitants of the earth, according to their different situations.

Ch. At the poles the circumstances, I suppose, are still different.

Fa. There one half of the ecliptic never sets, and the other half never rises; consequently the sun continues one half year above the horizon, and the other half below it. The full moon, being always opposite to the sun, can never be seen to the inhabitants of the poles, while the sun is above the horizon: but, all the time that the sun is below the horizon, the full moon never sets: consequently to them the full moon is never visible in summer; and in their winter they have her, always before and after the full, shining, for 14 of our days and nights, without intermission: and when the sun is depressed the lowest under the horizon, then the moon ascends with her highest altitude.

Ja. This indeed exhibits, in a high degree, the beneficence of the Almighty to all his creatures. But, if I understand you, the inhabitants of the poles have, in their winter, a fortnight's light and darkness, by turns.

Fa. This would be the case for the whole six months that the sun is below the horizon, if there were no refraction,* and no substitute for the light of the moon: but by the atmosphere's refracting the sun's rays, he becomes visible a fortnight sooner, and continues a fortnight longer in sight than he would otherwise do, were there no such property belonging to the atmosphere. And in those periods of the winter, when it would be absolutely dark in the absence of the moon, the brilliancy of the *Aurora Borealis* is so great as to afford a very comfortable degree of light. Mr. Hearne in his travels near the polar circle, makes the following remark in his Journal: "December 24. The days were so short, that the sun only took a circuit of a few points of the compass above the horizon, and did not at its greatest alti-

* The subject of refraction will be very particularly explained when we come to Optics.

tude rise half way up the trees. The brilliancy of the Aurora Borealis, however, and of the stars, even without the assistance of the moon, made amends for this deficiency; for it was frequently so light all night, that I could see to read small print."

QUESTIONS FOR EXAMINATION.

Why does the moon rise about three quarters of an hour later on each day than on that preceding? — At what season of the year is the difference in the rising of the moon but trifling for several successive evenings? — Why is not this necessary at the equator? — In what signs of the ecliptic is the difference in the time of the moon's rising the least, and how many minutes is this on an average? — In what signs is the full-moon at the time of harvest? — Which is the harvest-moon, and which the hunter's moon? — Why have the people at the equator no harvest-moon? — To whom is the harvest-moon most remarkable? — Why is there no harvest-moon to those who live within the polar circles? — At what season does not the full moon rise, and what time does she not set at the polar circles? — What happens remarkable at the poles with regard to the sun and moon? — Is there any substitute for the light of the moon to the inhabitants at the poles, when she is below the horizon?

CONVERSATION XVIII.

OF MERCURY.

Father. Having fully described the earth and the moon, the former a primary planet, and the latter its attendant satellite, or secondary planet, we shall next consider the other planets in their order, with which, however, we are less interested.

MERCURY, you recollect, is the planet nearest the sun; and Venus is the second in order. These two are called inferior planets.

Ch. Why are they thus denominated?

Fa. Because they both revolve in orbits which are included *within* that of the earth; thus (fig. 2) Mercury makes his annual journey round the sun in the orbit *a;* Venus in *b;* and the earth, farther from that luminary than either of them, makes his circuit in *t*.

Ja. How is this known?

Fa. By observation: for by attentively watching the progress of these bodies, it is found that they are continually changing their places among the fixed stars, and that they

are never seen in opposition to the sun; that is, they are never seen in the western side of the heavens in the morning, when he appears in the east; nor in the eastern part of the heavens in the evening, when the sun appears in the west.

Ch. Then they may be considered as attendants upon the sun?

Fa. They may: Mercury is never seen from the earth at a greater distance from the sun than about 28 degrees, or about as far as the moon appears to be from the sun on the second day after her change: hence it is that we so seldom see him; and when we do, it is for so short a time, and always in twilight, that we are precluded from making sufficient observations to ascertain whether he has a diurnal motion on his axis, or not.

Ja. Would you, therefore, conclude that he has such a motion?

Fa. I think we ought to conclude that he has; because it is known to exist in all those planets upon which observations of sufficient extent have been made; and therefore we may surely infer, without much chance of error, that it belongs also to Mercury and likewise to the planet Herschel; the former from its vicinity to the sun, and the latter from its great distance from that body, having at present eluded the investigation of the most indefatigable astronomers.

Ch. At what distance is Mercury from the sun?

Fa. He revolves round that body, at about 36 millions of miles distance, in 88 days, nearly; and therefore you can now tell me how many miles he travels in an hour.

Ja. I can: for, supposing his orbit circular, I must multiply the 37 millions by 6,* which will give 222 millions of miles for the length of his orbit; this I shall divide by 88, the number of days he takes in performing his journey; and the quotient resulting from this must be divided by 24, for the number of hours in a day: and by these operations I find that Mercury travels at the rate of more than 105,000 miles in an hour.

Ja. How long is Mercury in revolving round his axis?

Fa. He is supposed to revolve about his axis in 24 h. 5 m.

* See p. 126.

28 sec. He exhibits, also, phases which are discernible by a good telescope.

Ch. How large is Mercury?

Fa. He is the smallest of all the planets. His diameter, compared with that of the earth, taken as unity, is about 3140 miles: and his orbit is inclined to the ecliptic in an angle of 7° 0′ 9″.

Ja. His situation being so much nearer to the sun than ours, he must enjoy a considerably greater share of its heat and light.

Fa. So much so, that were the earth similarly situated, water could only exist in a state of vapour; metals also would be liquefied; everything, in fact, belonging to it would be burnt to atoms.

Ch. When is the best time for making observations on that planet?

Fa. The best time is when he passes before the sun, in the form of a black spot. This passage of a planet before the face of the sun is called its "Transit." The last Transit of Mercury happened on the 8th of May, 1845. Others will happen November 9, 1848; November 11, 1861; November 4, 1868; May 6, 1878; November 8, 1881: May 10, 1891; and these are all that will happen in the present century

These Transits demonstrate, that Mercury is an opaque body, like the earth, and that it receives its light from the sun, and exhibits different phases like the moon. The heat of the sun at Mercury must be seven times greater than our greatest summer heat.

Ch. And can you imagine that, thus circumstanced, this planet can be inhabited?

Fa. Not by such beings as we are. You and I could not long exist at the bottom of the sea; yet the sea is the habitation of millions of living creatures. Why, then, may there not be inhabitants in Mercury, fitted for the enjoyment of the situation which that planet is calculated to afford? Not that I mean to imply by this allusion that Mercury is as fluid as the sea. If, however, it is uninhabited, we must wonder why such a body was formed. Certainly it could not be intended, as far as our limited faculties can imagine, for our benefit. for it is rarely even seen by us.

QUESTIONS FOR EXAMINATION.

Which of the planets is nearest the sun? — Which are called inferior planets, and why are they so called?— How is it known that the orbits of Venus and Mercury are included within the orbit of the earth? — Why are they called attendants upon the sun? — Is Mercury frequently visible? — Does it, like the earth, turn on its axis? — At what distance is Mercury from the sun, and what is the length of his year? — At what rate does this planet travel in an hour? — How large is Mercury? — What degree of light and heat does he enjoy from the sun? — Is it probable that Mercury is inhabited? — When is the best time to make observations on Mercury? — What is meant by the transit of a planet?

CONVERSATION XIX.

OF VENUS.

Father. We now proceed to Venus, the second planet in the order of the solar system, but by far the most brilliant of them all.

Ja. How far is Venus from the sun?

Fa. She is about 68 millions of miles from the sun, and finishes her journey in 224$\frac{1}{4}$ days: consequently she must travel at the rate of 75,000 miles in an hour.

Ch. Venus is larger than Mercury, I imagine.

Fa. Yes; she is nearly as large as the earth, which she resembles in some respects; her diameter being about 7700 miles in length, but this is very variable, depending on her distance from the sun, which is very changeable, and she has a rotation about her axis, according to Shroeter, of 23 hours 21 min. 40 sec. The light and heat which she enjoys from the sun must be double that which is experienced by the inhabitants of this globe.

Ja. Is there a difference in her seasons, as there is here?

Fa. Yes; and in a much more considerable degree. The axis of Venus inclines about 75 degrees, but that of the earth inclines only 23$\frac{1}{2}$ degrees; and as the variety of the seasons, in every planet, depends on the degree of the inclination of its axis, it is evident that the seasons must vary more with Venus than with us.

Ch. Venus appears to us to be sometimes larger than at others.

Fa. True; and this, with other particulars, I will explain

by means of a figure. Suppose s to be the sun, T the earth in her orbit, and *a*, *b*, *c*, *d*, *e*, *f*, Venus in hers; now, it is evident that, when Venus is at *a*, between the sun and earth, she must appear much larger than when she is at *d*, in opposition.

Fig. 17.

Ja. That is because she is so much nearer in the former case than in the latter, being in the situation *a*, but 27 millions of miles from the earth T; but at *d* she is 163 millions of miles from us.

Fa. Now as Venus passes from *a*, through *b*, *c*, to *d*, she may be observed, by means of a good telescope, to have all the same phases as the moon has in passing from new to full: therefore, when she is at *d*, she is full, and is seen among the fixed stars in the beginning of Cancer. During her journey from *d* to *e*, she proceeds with a *direct* motion in her orbit, and at *e* she is seen in Leo, and will appear, to an inhabitant of the earth, for a few days to be *stationary*, not seeming to change her place among the fixed stars; for she is coming toward the earth in a direct line: but, in passing from *e* to *f*, though still with a direct motion, to a spectator at T, her course will seem to be *retrograde;* or to have gone back from *z* to *y*, till she gets to *c*, when she will again appear *stationary;* and afterwards, from *c* to *d*, and from *d* to *e*, it will be *direct*, among the fixed stars.

Ch. When is Venus an evening star, and when a morning star?

Fa. She is an evening star all the while she appears *east* of the sun, and a morning star while she is seen *west* of him. The Greeks gave her the name of *Hesperus*, when an evening star, and *Phosphorus* when a morning star; these names are from the words *hesperia* (ἑσπερια) "the evening," and *phos* (φως) "light," and *phero* (φερω) "I bring." She is sometimes called *Vesper*, the Latin word for *evening;* and *Lucifer*, from two Latin words, *lux* "light," and *fero* "I bring."

When she is at *a*, she will be invisible, her dark side being towards us, unless she be exactly in the node; in which case she will pass over the sun's face and appear like a little black

spot; indeed, she presents the same phenomena with Mercury, and in like manner crosses the sun's disc, which happened only twice during the last century; viz., in 1761 and in 1769. The next Transit will happen on December 8, 1874, and another on the 6th of December, 1882, both of which will be visible in Great Britain.

Ja. Is that called the transit of Venus?

Fa. It is; and it happens twice only in about 120 years, and must be when she is at her inferior conjunction, and very near one of her nodes. By this phenomenon astronomers have been enabled to find the sun's parallax, and so ascertain with great accuracy the distance of the earth from the sun; and, having obtained this, the distances of all the other planets are easily found. By the two transits which happened in 1761, and 1769, it was clearly demonstrated that the mean distance of the earth from the sun was between 95 and 96 millions of miles.

Ch. How do you calculate the distances of the other planets from the sun by knowing that of the earth?

Fa. I will endeavour to make this plain to you. Kepler, a great astronomer, discovered that all the planets are subject to three general laws; of which the one having reference to our particular subject is, that "*the squares of their periodical times, or that of their revolutions, are proportioned to the cubes of their mean distances from the sun.*"

Ja. What do you mean by the *periodical times?*

Fa. I mean the times which the planets take in revolving round the sun. Thus the periodical time of the earth is 365¼ days; that of Venus 224¼ days; and that of Mercury 88 days.

Ch. How, then, would you find the distance of Mercury from the sun?

Fa. By the rule of three. I would say, as the square of 365 days (the time which the earth takes in revolving about the sun) is to the square of 88 days (the time in which Mercury revolves about the sun), so is the cube of 95 millions (the distance in miles of the earth from the sun) to a fourth number.

Ja. And is that fourth number the distance, in miles, of Mercury from the sun?

Fa. No: you must extract the cube root of that number; and then you will have about 37 millions of miles for the answer; which is the true distance at which Mercury revolves about the sun.

Ch. What is the meaning of *Parallax,* Papa?

Fa. The term *Parallax,* from the Greek word *parallaxis* (παραλλαξις) "change," implies a change of place, or of aspect, and is the difference between the *apparent* place of a celestial object, and its *true* place as would be seen by a person at the centre of its motion; and when this is found we are enabled to determine the distance, real magnitude, and also the diameter of the body.

QUESTIONS FOR EXAMINATION.

How is the planet Venus described? — At what distance is Venus from the sun, and what is the length of her year? — How many miles does she travel in an hour? — What is the magnitude of this planet? — What proportion of light and heat does she enjoy? — Is there much difference in the seasons of this planet, and to what is that ascribed?— Explain to me by means of fig. 17, why Venus appears larger sometimes than she does at others. — Is Venus to be seen in different parts of her orbit with different phases like the moon? — Explain the different situations in which the motion of this planet is direct; when she seems to be *stationary,* and when her motion appears *retrograde.*— When is Venus an evening and when a morning star? — What is meant by the transit of Venus? — How often does a transit happen? — What is Kepler's law? — What is meant by the periodical times?

CONVERSATION XX.

OF MARS.

Father. Next to Venus is the earth, and her satellite, the moon: but of these sufficient notice has already been taken; and therefore we shall pass on to the planet Mars, the fourth in order from the sun, and which is known in the heavens by a dusky red appearance. Mars, together with Jupiter, Saturn, and Herschel, are called superior planets; because the orbit of the earth is inclosed by their orbits.

Ch. At what distance is Mars from the sun?

Fa. About 142 millions of miles. The length of his year is equal to nearly 687 of our days; and therefore he travels at the rate of more than 53 thousand miles in an hour: his diurnal rotation on his axis is performed in 24 hours, 39 min. and 21 sec.; which makes his figure that of an oblate spheroid: and his *synodine* revolution, or return to the same position in respect to the earth and sun, is nearly 780 days: and the inclination of his axis to the ecliptic is 30° 18′.

Ja. How is the diurnal motion of this planet discovered?

Fa. By means of a very large spot which is seen distinctly on his disc, when he is in that part of his orbit which is opposite to the sun and earth.

Ch. Is Mars as large as the earth?

Fa. No: his diameter is but 4100 miles; which is but little more than half the space of the earth's diameter: and in consequence of his distance from the sun, he will not enjoy one half so much of light and heat as we enjoy.

Ja. And yet, I believe, he has not the benefit of a moon.

Fa. No moon has ever been discovered belonging either to Mercury, Venus, or Mars.

Ch. Do the superior planets exhibit appearances of direct and retrograde motion similar to those of the inferior planets?

Fa. Yes: Suppose, s, the sun; *a*, *b*, *d*, *f*, *g*, *h*, the earth, in different parts of its orbit, and *m*, Mars in his orbit. When the earth is at *a*, Mars will appear among the fixed stars at *x*. When, by its annual motion, the earth has arrived at *b*, *d*, and *f*, respectively, the planet Mars will appear in the heavens at *y*, *z*, and *w*. When it has advanced to *g*, it will appear stationary. To the earth, in its journey from *g* to *h*, the planet will seem to go backwards, or retrograde in the heavens from *o* to *z;* and this retrograde motion will be apparent till the earth has arrived at *a*, when the planet will again appear stationary.

Fig. 18.

Ja. I perceive that Mars is retrograde when in *opposition;* and the same is, I suppose, applicable to the other superior planets; but the retrograde motion of Mercury and Venus is when those planets are in *conjunction.*

Fa. You are right: and you see the reason, I dare say, why the superior planets may be in the West in the morning, when the sun rises in the East, and the reverse.

Ch. For when the earth is at *d*, Mars may be at *n:* in which case the earth is between the sun and the planet. I observe also that the planet Mars, and consequently the other

superior planets, are much nearer the earth at one time than at others.

Fa. The difference, with respect to Mars, is no less than 190 millions of miles; the whole length of the orbit of the earth. This will be a proper time to explain what is meant by the *heliocentric* longitude of the planets, referred to in the Ephemeris.

Ja. Yes; I remember you promised to explain this when you came to speak of the planets; I do not know the meaning of the word heliocentric.

Fa. It is a term used to express the place of any heavenly body, as seen from the sun; whereas the *geocentric* place of a planet is the position which it has when seen from the earth: *heliocentric* is from the Greek *helios* (ἥλιος) "the sun," and *centron* (κεντρον) "a centre;" and *geocentric* from *ge* (γη) "the earth," and *centron* (κεντρον) "a centre."

Ch. Will you show us, by a figure, in what this difference consists?

Fa. I will: let s represent the place of the sun; *b* Venus in its orbit; *a* the earth in hers; and *c* Mars in his orbit; and the outermost circle will represent the sphere of fixed stars. Now, to a spectator on the earth, *a*, Venus will appear among the fixed stars in the beginning of Scorpio; but, as viewed from the sun, she will be seen beyond the middle of Leo. Therefore the *geocentric* longitude of Venus will be in Scorpio, but her *heliocentric* longitude will be in Leo.

Fig. 19.

Again, to a spectator at *a*, the planet Mars, at *c*, will appear among the fixed stars towards the end of the sign Pisces; but, as viewed from the sun, he will be seen at the beginning of the sign Aries: consequently the geocentric longitude of Mars is in Pisces; but his *heliocentric* longitude is in Aries.

Ch. How is the fiery redness of the light of Mars accounted for?

Fa. It is the opinion of Dr. Herschel that Mars is inhabited; and he has discerned distinctly the outlines of con-

tinents and seas. It is the construction of the former, he thinks, which gives the planet the ruddy appearance it has, and from the seas is reflected a greenish hue. He has also observed brilliant white spots upon its poles which he imagines to be snow; for they disappear when they have been long exposed to the sun, and are more extended and distinguishable when just emanating from their winter season.

QUESTIONS FOR EXAMINATION.

What are the superior planets, and why are they so called? — At what distance is Mars from the sun, and what is the length of his year? — How was the diurnal rotation of this planet discovered? — What is the magnitude of Mars, and what proportion of light and heat does he enjoy from the sun? — Explain by fig. 18 the direct and apparent retrograde motions of the superior planets. — Tell me why the superior planets may be in the west in the morning, when the sun rises in the east, and the reverse. — How much nearer to the earth is Mars than the other superior planets at one time than at another? — What is meant by the *heliocentric* longitude of a planet? — What is the *geocentric* place of a planet? — Explain by fig. 19 in what the difference between the heliocentric and geocentric longitude of the planets consists.

CONVERSATION XXI.

OF THE SMALL PLANETS, AND OF JUPITER.

Father. Next to Mars we come to fifteen of the more recently discovered planets. I told you, in Conversation V., that there were altogether twenty-three planets. Of these the orbits of three are within that of Mars, those of fifteen are between those of Mars and Jupiter, and the orbits of three are beyond that of Jupiter. Now, can you tell me the respective distances of these fifteen from the sun, the length of their annual revolutions, and whence they derived their names?

Ch. I think so.

Flora has a period of revolution equal to 1193 days, being the shortest of any of her companion planets; her mean distance from the sun being 209,826,000 miles. Her name was given her by Sir J. Herschel, and a flower, the "Rose of England," was chosen as her symbol.

Victoria has a period of 1302 days; and her mean distance is 222,373,000 miles. She received her name in honour of our queen: the rule hitherto followed in regard to the

minor planets requiring a female name, taken from either the Greek or the Roman mythology.

VESTA performs her revolution in 3·6284 years, at a mean distance of 225,000,000 miles. She was named after the goddess Vesta, the daughter of Saturn, and sister to Ceres and Juno.

METIS requires 3·686 years for her revolution, and her mean distance is 227,387,000 miles. Metis, in Grecian mythology, was the first wife of Jupiter, she was one of the Oceanides or sea-nymphs.

IRIS requires 3·6844 years, or 1346 days, and the mean distance is 227,334,000 miles. Iris was named after the sea-nymph of that name, also one of the Oceanides.

HEBE takes 3·7761 years, and the distance is 231,089,000 miles. Hebe, in mythology, was a daughter of Jupiter and Juno.

PARTHENOPE, 1401 days, or 3·838 years; and the mean distance, 233,611,000 miles. Here name was adopted from that of one of the Sirens. The ancient name of the city of Naples, the residence of M. de Gasparis, the discoverer of this planet, was Parthenope.

ASTRÆA has a period of revolution of 1511 days, and a mean distance of 245,622,000 miles. The mythological Astræa was the goddess of Justice, and during the iron age she was driven to heaven by the wickedness and impiety of mankind.

EGERIA, 1505 days, and 244,940,000 miles. The nymph Egeria was the councillor of Numa Pompilius.

IRENE, 4·15 years, and 246,070,000 miles. Irene was one of the daughters of Jupiter, and her name was adopted in allusion to the peace prevailing in Europe at the time of the discovery of the planet.

EUNOMIA, 1574 days, or 4·308 years, and 252,300,000 miles. Eunomia was a sister of Irene.

JUNO, 4·3594 years, and 253,312,000 miles. Juno was the daughter of Saturn, and sister to Jupiter, Neptune, Vesta, and Ceres.

CERES, 4·6033 years, and 263,713,000 miles.

PALLAS, 1687 days, or 4·6175 years, and 284,256,000 miles. Pallas was a daughter of Jupiter.

HYGEIA, 2044 days, or 5·594 years, and 300,322,000 miles. Hygeia was the goddess of health.

Fa. There are three planets, as I told you, whose orbits

are beyond that of Jupiter, viz., Saturn, Uranus, and Neptune: these we shall consider directly; but I shall take this opportunity of stating to you, that the mean distance of Neptune from the sun is 2,862,457,000 miles, and its period of revolution 6,012,671 days, or rather more than 164½ years.

Ch. Who discovered Neptune?

Fa. The question is incapable of a direct answer.

The discovery of Neptune forms one of the most beautiful illustrations of the exactness and dependency to be placed upon astronomical investigations, and marks in a signal manner the maturity of astronomical science. The proof, or at least strong presumption, of the existence of a planet occupying the position of Neptune, as a means of accounting, by its attraction, for certain irregularities observed in the motions of Uranus, was afforded almost simultaneously by Mr. Adams, of Cambridge, and M. Leverrier, of Paris. These philosophers were enabled, *from theory alone*, to calculate whereabouts it ought to appear in the heavens, *if visible*, the places thus independently calculated agreeing surprisingly. A letter being sent by M. Leverrier to M. Galle, of Berlin, requesting him to look for a planet in that spot in the heavens, this gentleman did so, and discovered Neptune on the same evening. This remarkable verification of an indication so extraordinary took place on the 23rd of September, 1846.

The relative sizes of these planets have not been accurately determined; nor can this be wondered at, considering how recently several of them have been discovered. But the following illustration, by Sir J. Herschel, will give a general notion of that of some of them. Choose any well-levelled field or bowling-green. On it place a globe, two feet in diameter; this will represent the sun; Mercury will be represented by a grain of mustard seed, or the circumference of a circle 164 feet in diameter for its orbit; Venus, a pea, on a circle 284 feet in diameter; the earth, also a pea, on a circle of 430 feet; Mars, a rather large pin's head, on a circle of 654 feet; Juno, Ceres, Vesta, and Pallas, grains of sand, in orbits of from 1000 to 1200 feet; Jupiter, a moderate-sized orange, in a circle nearly half-a-mile across; Saturn, a small orange, on a circle of four-fifths of a mile; Uranus, a full-sized cherry, or small plum, upon a circumference of a circle more than a mile and a half; and Neptune, a good-sized plum, on a circle about two and a half miles in diameter.

Fa. We proceed now to Jupiter, the largest of all the planets, which is easily known by his peculiar magnitude and brilliancy.

Ch. Is Jupiter larger than Venus?

Fa. Though he does not appear so large, yet the magnitude of Venus bears but a very small proportion to that of Jupiter, whose diameter is 87,000 miles, eleven times that of the earth, consequently, his bulk will exceed that of the earth 1300 times. His distance from the sun is estimated at nearly 490 millions of miles.

Ja. Then he is more than *five* times further from the sun than the earth, and consequently, as light and heat diminish in the same proportion as the distances from the illuminating body increase, the inhabitants of Jupiter enjoy but a twenty-fifth part of the light and heat, afforded by the sun, that we enjoy.

Fa. Another thing remarkable in this planet is, that he revolves on his axis, which is perpendicular to his orbit, in 9 hours, 55 min. 50 sec.; and, in consequence of this swift diurnal rotation, his equatorial diameter is 6000 miles greater than his polar diameter, and found to be in the proportion of 15 to 14.

Ch. Since, then, a variety in the seasons of a planet depends upon the inclination of the axis to its orbit, and since the axis of Jupiter has no inclination, there can be no difference in his seasons, nor any in the length of his days and nights.

Fa. You are right: his days and nights are always five hours each in length; and at his equator and its neighbourhood there is perpetual summer, and in his polar region a continual winter.

Ja. What is the term of his annual revolution?

Fa. It is equal to nearly 12 of our years; for he takes 11 years, 317 days, 14 hours, 2 min. and 8½ sec. to make a revolution round the sun; consequently he travels at the rate of more than 28,000 miles in an hour.

This immense planet is accompanied by four satellites, which revolve about him, nearly in the plane of his equator, exactly in the same manner as the moon revolves round the earth, and at different distances, and in different periodical times; the *first* in about 1 day and 18 hours; the *second* in 3

days, 13 hours; the *third* in 7 days, 3 hours; and the *fourth* in 16 days and 16 hours. They were discovered by Galileo in 1610, immediately after the invention of the telescope. They are also of considerable magnitude compared with the earth; their diameters may be estimated as follows;—that of the *first* rather less than $\frac{1}{3}$ of that of the earth; of the *second*, $\frac{1}{4}$; of the *third*, $\frac{1}{2}$, which is about the size of Mars; and of the *fourth*, rather more than $\frac{1}{3}$.

Ch. And are these satellites, like our moon, subject to eclipses?

Fa. Yes: and they can be observed with the greatest precision; these eclipses also are of considerable importance to astronomers in ascertaining with accuracy the longitude of different places on the earth, and in determining the sidereal and synodical revolutions of the satellites.

By means of the eclipses of Jupiter's satellites, a method was also obtained by Roemer of demonstrating that the motion of light is *progressive*, and not *instantaneous*, as was once supposed; for the eclipses and emersions of Jupiter's satellites become visible about 16 min. 26 sec. earlier when the earth is at its least distance from Jupiter, than when it is at its greatest. Hence it is found that the velocity of light is nearly 11,000 times greater than the velocity of the earth in its orbit, and more than a million of times greater than that of a ball fired from a cannon. It is estimated at 192,000 miles a second, so that rays of light occupy above a quarter of an hour in passing through the diameter of the earth's orbit.

Ch. In looking through a telescope at this planet we observe several dark streaks across his disk, parallel to his equator; what are they, Papa?

Fa. Those streaks are called the *belts* of Jupiter; and they vary in their appearance at different times, both as to their breadth and their situation; spots have also been seen upon them, whence it has been imagined that these peculiarities are in the atmosphere of the planet, and produced by a strong current, analogous, in some respects, to our trade-winds. Dr. Herschel thinks it is the comparatively darker body of the planet that is presented to view in these streaks, because they do not appear of so decisive a character on the edge of the disk, but gradually fade away as they approach it.

QUESTIONS FOR EXAMINATION.

What are the smaller planets? — When and by whom were they discovered? — How is Jupiter known? — What is the magnitude of Jupicer, and what is his distance from the sun? — What proportion of light and heat does he enjoy from that luminary? — What is the length of his days and nights? — Is there anything remarkable with regard to this planet? — Is there any difference of seasons, or in the length of day and night, in Jupiter? — What is the length of Jupiter's year, and at what rate does he travel? — How many moons has Jupiter? — To what practical purpose have the eclipses of Jupiter's moons been applied?

CONVERSATION XXII.

OF SATURN.

Father. We are now arrived at Saturn, which, previous to the discovery of Herschel, was esteemed the most remote planet of the solar system; his appearance is less brilliant than that of Jupiter or of Venus.

Ch. How is he distinguished in the heavens?

Fa. He shines with a pale dead light, very unlike the brilliancy of Jupiter; yet his magnitude seems to vie with that of Jupiter himself. The diameter of Saturn is nearly 80,000 miles: his distance from the sun is about 890 millions of miles; and he performs his journey round that luminary in about 29½ of our years: consequently he must travel at a rate not much short of 21,000 miles in an hour.

Ja. His great distance from the sun must render an abode on Saturn extremely cold, and dark too, in comparison with what we experience here.

Fa. His distance from the sun being between 9 and 10 times greater than that of the earth, he must enjoy about 100 times less light and heat. It has nevertheless been calculated that the light of the sun at Saturn is 500 times greater than that which we enjoy from our *full moon.*

Ch. The day-light at Saturn, then, cannot be very contemptible. I should hardly have thought that the light of the sun there was 500 times greater than that experienced from a full moon.

Fa. So much greater is our meridian light than this, that, during the sun's absence behind a cloud, when the light is

much weaker than when we behold him in all his glorious splendour, it is reckoned that our day-light is 90,000 times greater than the light of the moon at its full.

Ja. But Saturn has several moons, I believe.

Fa. He is attended by *seven* satellites or moons, whose periodical times differ very much. The following table will show you the mean distances of each satellite from Saturn, and give you also their periods of sidereal revolution.

Satellite.	*Mean Distance.*	*Periodic Time.* d.	h.	m.
1	3·351	0	22	38
2	4·300	1	8	53
3	5·284	1	21	18
4	6·819	2	17	45
5	9·524	4	12	25
6	22·081	15	22	41
7	64·359	79	7	55

The most distant satellite was discovered by Huygens in 1665; four others by Dominic Cassini about 20 years later; while the two interior ones, which can only be seen under very peculiar circumstances, and by the most powerful telescopes, were discovered by Dr. Herschel in 1789. The seventh satellite is by far the largest, and is known to turn on its axis, and in its rotation is subject to the same law which our moon obeys; that is, it revolves on its axis in the same time that it revolves about the planet.

Besides these seven moons, Saturn is encompassed with two broad *rings*, which are probably of considerable importance in reflecting the light of the sun to that planet. Dr. Herschel gives the dimensions of these rings as follows:—

	Miles.
Exterior diameter of exterior ring . . .	176,418
Interior ditto . . .	155,272
Exterior diameter of interior ring . . .	151,690
Interior ditto . . .	117,339
Equatorial diameter of the body	79,160
Interval between the planet and interior ring	19,090
Interval of the rings	1,791
Thickness of the rings not exceeding . .	100

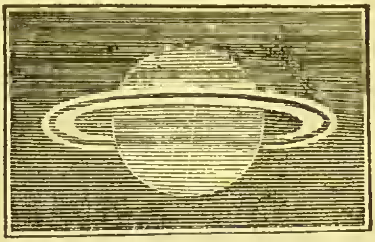

Fig. 20.

These rings give Saturn a very different appearance from any of the other planets. Fig. 20 is a representation of Saturn, as seen through a good telescope; and from the circumstance of the ring casting a dark shadow on the planet on the side nearest the sun, and receiving the shadow of the planet on the opposite side, there can be no doubt but that the ring is composed of some solid and ponderous material; while as to its usefulness, all must at present rest on conjecture.

Ch. Is it known whether Saturn turns on its axis?

Fa. According to Dr. Herschel, it has a rotation about its axis in 10 hours 29 min. 16·8 sec. This he computed from the equatorial diameter being greater than the polar diameter, in the proportion nearly of 11 to 12. Dr. Herschel has also discovered that the ring just mentioned revolves about the planet in 10 hours and a half.

Saturn has a diameter of 76,068 miles, consequently he is nearly 1000 times larger than the earth.

QUESTIONS FOR EXAMINATION.

How is Saturn distinguished in the heavens? — How large is Saturn, and at what distance is he from the sun?— What is the length of his year, and at what rate does he travel? — What proportion of light and heat does he enjoy from the sun? —Do you recollect how much greater daylight is than the light of the moon at its full? — How many moons has Saturn? — What other peculiarities are noticed with regard to Saturn? — Is the length of Saturn's day and night known?

CONVERSATION XXIII.

OF HERSCHEL OR URANUS.

Father. We have but one other planet to describe: that is Herschel.

Ja. Was it discovered by Dr. Herschel?

Fa. It was, on the 13th of March, 1781, and therefore, by astronomers in general, as mentioned in a former conversation, it was denominated the planet Herschel. It is, however, now more usually called *Urănus*, a word derived from the Greek *ouranos* (ουρανος) " heaven." It had also been previously ob-

served by Flamstead, Bradley, Meyer, and Lemonnier, but they did not consider it to be a planet.

Ch. I do not think that I have ever seen this planet.

Fa. Its apparent diameter is too small to be discerned readily by the naked eye; but it may be easily discovered in a clear night, when it is above the horizon, by means of a good telescope; its situation being previously ascertained from the Ephemeris.

Ja. Is it owing to the smallness of this planet, or to its great distance from the sun, that we cannot see it with the naked eye?

Fa. Both these causes are combined. In comparison with Jupiter and Saturn, it is small; his diameter being about 35,000 miles, nearly four and a half times that of the earth; and his distance from the sun is estimated at more than 1800 millions of miles from that luminary, around which, however, he performs his journey in 84 of our years: consequently he must travel at the rate of 16,000 miles in an hour.

Ch. But if this planet was only discovered in 1781, how is it known that it will complete its revolution in 84 years?

Fa. By a long series of observations it was found to move with such a velocity as would carry it round the heavens in that period. Moreover, when it was discovered, it was in Gemini, and it is now advanced far among the signs of the Zodiac, almost a fourth part of its journey.

Ja. How many moons has the planet Herschel?

Fa. He is supposed to have six satellites or moons; but the existence of more than two is not clearly made out; one of these, the nearest to the planet, performs his revolution round the primary in 8 days, 16 hours, 56 min. and 31·3 sec.; and the other takes 13 days, 11 hours, 7 min. and 12·6 sec. for his journey.

Ch. Is there any idea formed as to the light and heat enjoyed by this planet?

Fa. His distance from the sun is 19 times greater than that of the earth; consequently, since the square of 19 is 361, the light and heat experienced by the inhabitants of that planet must be 361 times less than we derive from the rays of the sun.

The proportion of light enjoyed by the planet Herschel has been estimated at about equal to the effect of 248 of our full moons. This planet is about 80 times larger than the earth

QUESTIONS FOR EXAMINATION.

Is the planet Herschel easily distinguished? — How large is this planet, and at what distance is he from the sun? — What is the length of his year, and at what rate does he travel? — How many moons has the planet Herschel? — What is the proportion of light and heat which this planet enjoys from the sun?

CONVERSATION XXIV.

OF COMETS.

Father. Besides the eleven primary planets, and the eighteen secondary ones, or satellites, which we have been describing, there are other bodies belonging to the solar system, called comets.

Ch. Do comets resemble the planets in any respects?

Fa. Like them, they are supposed to revolve about the sun in elliptical orbits, very elongated, and to describe equal areas in equal times; and they are only visible during the short time they are in the perihelia of their orbits, and they do not appear to be adapted for the habitation of animated beings, owing to the great degrees of heat and cold to which they, in their course, must be subjected from this great eccentricity of their orbit; nor do they travel like the planets from west to east, but in all directions indifferently.

The comet seen by Sir Isaac Newton in the year 1680, immediately after its perihelian passage, was observed to approach so near the sun, that its heat was estimated by that great man to be 2000 times greater than that of red-hot iron: and further, that its length amounted to the enormous extent of 41,000,000 leagues.

Ja. It must have been a very solid body to have endured such a heat without being entirely dissipated.

Fa. So, indeed, it should seem: and a body thus heated must retain its heat a long time; for a red-hot globe of iron, of a single inch in diameter, exposed to the open air, will scarcely lose all its heat in an hour; and it is said, that a globe of red-hot iron, as large as our earth, would scarcely cool in 50,000 years.*

Ch. Are comets numerous, and their periodical times wel known?

* See Enfield's Institutes of Natural Philosophy, p. 296. 2nd edition.

Fa. The orbits of 129 comets have been determined; but only 68 have a direct motion; the remaining 61 have been found to have a retrograde motion, and, what is surprising, their orbits intersect the ecliptic in every imaginable angle. However, out of all this number there are but three whose returns to the sun in successive revolutions have been verified by actual observation, and brought within any degree of certainty. The first is named *Halley's* comet, the return of which is in every 75 years. The second, *Encke's* comet, whose return is in about $3\frac{1}{3}$ years; and thirdly, *Biela's* comet, which returns in about 6 years and 8 months.

The *first* of these appeared in the years 1531, 1607, 1682, 1759, and in 1835; it took its name from Dr. Halley, who applied Newton's laws and established its periodical returns.

The second, or *Encke's* comet, so named from Professor Encke of Berlin, who computed its elliptic elements, appeared in 1789, 1795, 1801, and 1805: but its periodic returns were not established till 1819. It was visible in 1825, 1828, and 1832, but from observations it is thought that its period of return is continually diminishing.

The third, or *Biela's* comet, named after its discoverer, who was an Austrian officer, appeared in 1772, 1789, 1795, 1832 1839, and in 1846. It is a small comet, having no tail.

Some comets have been observed, whose *greatest* distance was eleven thousand two hundred millions of miles from the sun; and whose *least* distance from the sun's centre was but forty-nine thousand miles; and in this part of its orbit it travelled at the immense rate of 880,000 miles in an hour.

Ja. Do all bodies move faster or slower in proportion as they are nearer to, or more distant from, their centre of motion?

Fa. They do: for if you look back upon the last six or seven lectures, you will see that the planet Herschel, which is the most remote planet in the solar system, travels at the rate of 16,000 miles an hour; Saturn, the next in order, 21,000, miles; Jupiter, 28,000 miles; Mars, 53,000 miles; the earth, 65,000 miles; Venus, 75,000 miles; and Mercury at the rate of 105,000 miles in an hour. But here we come to a comet, whose progressive motion, in that part of its orbit which is nearest to the sun, is more than equal to eight times the velocity of Mercury.

Ch. Why are they called *comets*, Papa?

Fa. The word *comet* is derived from the Greek *come* (κομη) "hair:" and has been applied to these heavenly bodies from the circumstance of their having the appearance of being attended by a beard or *hair*. The central and more luminous part is called the *nucleus:* if this nucleus is encircled by a nebulous appearance, it is called a *haired* comet: if a nebulosity or luminous tail follows the comet like a train, it is called a *tailed* comet; if the nebulosity precedes, it is called a *bearded* comet. But these distinctions are not observed in modern works on astronomy: for whether they have any nebulosity or tail, or not, they are simply called *comets.*

Ch. Of what are comets constructed? Are they supposed to be of the same nature as the planets, or the stars?

Fa. The physical constitution of comets, though it has been subject to the most learned inquiry, is still involved in much obscurity; and Dr. Herschel adds, that no rational or plausible explanation has been yet offered in respect of the *tail.* It is extremely probable that the comets are merely collections of gaseous matter: the *nucleus*, when seen through the most powerful telescopes, seems to have no solidity, though in some a minute stellar point has been observed bearing the character of a solid body; and the luminous appendage also seems to have the nature of smoke, fog, or cloud, yet still all is, at present, hypothetical.

Ch. Were not comets formerly dreaded, as awful prodigies, exciting great alarm among the inhabitants of the world?

Fa. Yes; to uninformed people they have been a source of terror, from a superstitious notion of their foreboding evil to the world, of being the harbingers of indefinite and unavoidable calamity.

QUESTIONS FOR EXAMINATION.

In what respects do comets resemble the planets? — What is said of the comet seen by Sir I. Newton in 1680? — Is there anything known with certainty in regard to the periodical times of comets? — How is it shown that all bodies move faster or slower in proportion as they are nearer to, or more distant from, their centre of motion? — What is the nature of comets; and why are they so called? — Explain their different parts.

CONVERSATION XXV.

OF THE SUN.

Father. Having given you a particular description of the planets which revolve about the sun, and also of the satellites which travel round the primary planets as central bodies, while they are carried at the same time with these bodies round the sun, we shall now take some notice of the sun himself.

Ja. You told us, a few days ago, that the sun has a rotation on its axis. How is that known ?

Fa. By the many dark spots on his surface, it is ascertained that he completes a revolution from West to East on his axis in about 25 days, two days less than his *apparent* revolution, in consequence of the earth's motion in her orbit, in the same direction.

Ch. Is the figure of the sun globular ?

Fa. No; the motion about its axis renders it spheroidal, having its diameter at the equator greater than that which passes through the poles.

The sun's diameter is estimated at 892,000 miles, which is equal to upwards of 100 diameters of the earth ; and therefore his bulk is about 1,400,000 times greater than that of the earth: but the density of the matter of which it is composed is four times less than the density of our globe, yet his volume is 500 times greater than that of all the planets taken together.

We have already seen that, by the attraction of the sun, the planets are retained in their orbits, and that to him they are indebted for light, heat, and motion.

Ch. What, Papa, did you say was the distance of the sun from the earth ?

Fa. The sun is estimated to be 96 millions of miles from the earth, and were a cannon-ball of 24lbs. weight, to be impelled by about 8 lbs. of gunpowder, at the velocity of 1600 feet in a second, it would take ten years to reach the sun, if it proceeded with the same uniform velocity. *Sound* would take more than 13 years to pass from us to the sun; and *light*, which

travels at the rate of 192,500 miles in a second, occupies 8 min. 18 sec. to reach us from the sun.

Ch. Is the sun supposed to be inhabited, Papa?

Fa. Of all the orbs the sun we know is the most conspicuous and the most magnificent; and through him all the worlds are enlightened, and by his presence we behold the day.

The first thing that strikes the mind, in contemplating this brilliant orb, is its astonishing magnitude, which, as we have just observed, is more than a million times larger than our earth.

From the effects which this immense body has in enlightening and warming us, and in promoting vegetable and animal life, we should naturally be disposed to believe it were a vast body of fire; but this opinion, although it prevailed for ages, is now almost rejected.

Some astronomers consider it not improbable, that the sun may so nearly resemble the earth, as to be a suitable residence for rational and immortal beings. Others again consider it to be an immense furnace, but everything connected with this subject is conjecture, and we must at last exclaim, with many others, "the sun is a vast mystery."

QUESTIONS FOR EXAMINATION.

How is it known that the sun turns on its axis? — In what time is this revolution made? — What is the figure of the sun? — What is the size of this body? — What is the solar system? — Why so called? — What are the names of the several planets which constitute the solar system? — How many satellites or moons are there? — Which of the planets have moons? — Which have not? — Describe the sun. — What methods did astronomers adopt to obtain a knowledge of the distance of the sun from the earth? — Of what is it the source? — What constitutes day? — What night? — What is the diameter of the sun? — What his distance from the earth? — What is the opinion of philosophers as to what constitutes the body of the sun?

CONVERSATION XXVI.

OF THE FIXED STARS, AND OF THE SHOOTING STARS.

Father. We will now, before closing our Astronomical Conversations, refer again to the fixed stars, which, like our sun, shine by their own light.

Ch. Is it certain that the fixed stars are of themselves luminous bodies; and that the planets borrow their light from the sun?

Fa. By the help of telescopes it is seen that Mercury, Venus, and Mars shine by a borrowed light, for, like the moon, they are observed to have different phases according to their situation with regard to the sun. The immense distances of Jupiter, Saturn, and Herschel, do not allow the difference between the perfect and imperfect illumination of their discs or phases to be perceptible.

Now, the distance of the fixed stars from the earth is so great, that reflected light would be much too weak ever to reach the eye of an observer here.

Ja. Is this distance ascertained with any degree of precision?

Fa. It is not: but it is known with certainty to be so great, that the whole length of the earth's orbit (viz. 190 millions of miles) is but a point in comparison of it: and hence it is inferred, that the distance of the nearest fixed star cannot be less than a hundred thousand times the extent of the earth's orbit;* that is, a hundred thousand times 190 millions of miles, or 19,000,000,000,000 miles. This distance being immensely great, the best method of forming some clear conception of it is to compare it with the velocity of some moving body by which it may be measured. The swiftest motion we are acquainted with is that of light; which, as we have seen, is at the rate of 12 millions of miles in a minute: and yet light would be about three years in passing from the nearest fixed star to the earth.

A cannon-ball, which may be made to move at the rate of 20 miles in a minute, would be 1800 thousand years in traversing this distance. Sound, the velocity of which is 13 miles in a minute, would be more than 2 million 7 hundred thousand years in passing from the star to the earth. So that if it were possible for the inhabitants of the earth to see the light, to hear the sound, and to receive the ball of a cannon discharged at the nearest fixed star, they would not perceive the light of its explosion for three years after it had been fired; nor receive the ball till 1800 thousand years had elapsed; nor

* See Dr. Enfield's Institutes of Natural Philosophy, p. 347. Second edition.

hear the report for 2 millions and 7 hundred thousand years after the explosion.

Ch. Are the fixed stars at different distances from the earth?

Fa. Their magnitudes, as you have learned, appear to be different from one another; which difference may arise either from a diversity in their real magnitudes or in their distances, or from both conjointly. It is the opinion of Dr. Herschel, that the different apparent magnitudes of the stars arise from the different distances at which they are situated; and he therefore concludes that stars of the seventh magnitude are at seven times the distance from us that those of the first magnitude are.

By the assistance of his telescopes he is able to discover stars at 497 times the distance of *Sirius*, the Dog-star: from which he infers that with more powerful instruments he should be able to discover stars at still greater distances.

Ja. I recollect that you told us once, that it had been supposed, by some astronomers, that there might be fixed stars at so great a distance from us, that the rays of their light had not yet reached the earth, although they had been travelling at the rate of 12 millions of miles in a minute, from the first creation to the present time.

Fa. I did: it was one of the sublime speculations of the celebrated Huygens. Dr. Halley has also advanced what, he says, seems to be a metaphysical paradox; viz. that the number of fixed stars must be more than finite, and some of them at a greater than a finite distance from others: and Mr. Addison has justly observed, that this thought is far from being extravagant, when we consider that the universe is the work of Infinite Power, prompted by Infinite Goodness, and having an infinite space to exert itself in; so that our imagination can set no bounds to it. And Dr. Herschel's discoveries go very far to establish the truth of these conjectures.

Ch. What do you suppose is the use of these fixed stars to us on the earth? Not to enlighten the earth, I imagine; for a single additional moon would give us much more light, especially if it were so contrived as to afford us its assistance at those intervals when our present moon is below the horizon.

Fa. Your conjectures are reasonable: they do not seem to our shallow reasoning powers to have been created for our use, since thousands, and even millions, are never seen but by the

assistance of glasses, to which but few of our race have access: and I feel that your minds are too enlightened to imagine, like children unaccustomed to reflection, that all things were created for the enjoyment of man alone. The earth on which we live is but one of eleven primary planets circulating perpetually round the sun as a centre, and with which are connected eighteen secondary planets or moons, all of which are probably teeming with living beings, capable, though in different ways, of enjoying the bounties of the great First Cause: and which have been designed, beyond a doubt, for some great end, by the Omniscient Creator, too inscrutable for the presumptive reasoning of man.

The fixed stars, however, are probably suns, which, like our sun, serve to enlighten, warm, and sustain other systems of planets and their dependent satellites.

Ja. Would our sun appear as a fixed star at any great distance?

Fa. It certainly would: and Dr. Herschel thinks there is no doubt that it is one of the heavenly bodies belonging to that tract of the heavens known by the name of the *Milky Way.*

Ch. I know the milky way in the heavens; but I little thought that I had any concern with it otherwise than as an observer.

Fa. The milky way consists of fixed stars, too small to be discerned by the naked eye; and if our sun be one of them, the earth and other planets are closely connected with this part of the heavens.

But, my dear children, it is time that we should bring this subject to a conclusion. I must not, however, forget to notice those well-known meteors, the *Shooting Stars*, the origin and nature of which are involved in great obscurity, and which have of late years excited great interest by their periodical appearances in unusually great numbers. The apparent magnitudes of these meteors are widely different; the greater part of them resemble stars of the 3rd, 4th, 5th, and 6th magnitude, but some occur which surpass stars of the 1st magnitude, and even exceed Jupiter and Venus in brilliancy. They are observed at all times of the year, but generally speaking they appear to be more abundant towards the end of summer, and in the autumn, especially about

the 12th and 13th of November. Various hypotheses have been proposed to account for these remarkable phenomena; in general they have been regarded as meteors having their origin in the atmosphere, and electricity, magnetism, and hydrogen gas have in turn been assigned as their immediate causes. The hypothesis, however, first suggested by Chladni is that which appears to have met with most favour, having been adopted by Arago and other astronomers of the present day, to explain the November phenomena. It consists in supposing that independently of the great planets, there exist in the planetary region, myriads of small bodies, which circulate about the sun, generally in groups of zones, and that some of these zones intersect the ecliptic, and are consequently encountered by the earth in its annual revolution.

To-morrow I will give you a little account of the history of this most interesting and most valuable science, by way of a concluding summary, which I beg you to read attentively.

QUESTIONS FOR EXAMINATION.

What proofs are there that the planets borrow their light from the sun? — How is it known that the fixed stars shine by their own light? — Is the distance of the fixed stars known? — How long would a ray of light be in passing from the nearest fixed star to us? — Whence does the apparent magnitude of the fixed stars seem to arise? — At what distance has Dr. Herschel been able to discover stars? — What does Huygens say of the distances of the fixed stars? — What has Dr. Halley advanced respecting these bodies? For what important purposes can we suppose that the fixed stars were created? — In what situation would our sun appear as a fixed star? — To what tract of the heavens is our sun supposed to belong? — Of what does the milky-way consist? — What are the shooting stars? — On what hypothesis is their periodical appearance most naturally accounted for?

CONVERSATION XXVII.

HISTORY OF ASTRONOMY.

Charles. You promised, Papa, to give us a concise history of this interesting science of astronomy; can you do so to-day?

Fa. Yes; and I will read it to you; and I hope you will give it that attention which its importance deserves.

Astronomy is the science that describes the heavenly bodies; namely, the sun, moon, and stars, together with the

planets, comets, and other phenomena. It explains the figure and motion of the earth, the cause of day and night, and the variety of the seasons, the tides and eclipses. It is a science worthy of your highest consideration, and it is so beneficial in its effects to the mind of man, that it deserves our utmost attention, and claims our highest admiration.

By this sublime science we are enabled to explore the whole universe, so far as the human eye can reach, pursue the different planets in their uniform course, and also trace the laws by which they perform their evolutions with so much order and harmony.

These contemplations are worthy of every rational being, and have for many ages engaged the minds of the most enlightened men of every nation. Indeed there is no study that so readily leads man to a knowledge of his Creator, and the conviction of the duties he owes to God and society, as that of astronomy.

The science of astronomy was first cultivated by the Chaldeans, the Phœnicians, and Egyptians. It was from them that the Greeks derived their first knowledge of this science, as also that of several others.

Ja. Who was the first, Papa, that laid the foundation of astronomy among the Greeks?

Fa. Thales, a native of Miletus, in Asia Minor, B.C. 641, who predicted an eclipse, and explained its cause. He taught that the earth was round, and divided its surface into five zones; he discovered the solstices and equinoxes, and divided the year into 365 days.

The opinions of Thales were maintained and taught by his pupil Anaximander, who is said to have invented maps and dials, and also to have constructed a sphere.

Another of Thales' scholars was Pythagoras, who is supposed to have been a native of the island of Samos. Pythagoras travelled in quest of knowledge through Phœnicia, Chaldea, India, and Egypt. Having returned from the East, he visited his native island, but meeting with little encouragement, he passed over into Italy, and opened a school in the city of Crotona; where he taught publicly the vulgar doctrine, that the earth was the centre of the universe; but to his scholars, he communicated his real opinions, which were similar to those afterwards adopted by Copernicus, of Thorn,

in Prussia, and followed up by Sir Isaac Newton; namely, that the earth and all the planets move round the sun, as their centre; which doctrine Pythagoras is supposed to have derived from the Indians.

Among the most celebrated of the ancient astronomers, after Pythagoras, were Ptolemy of Alexandria, in Egypt, Aristarchus, Eratosthenes, and Hipparchus.

The school of Alexandria subsisted for about five hundred years after Ptolemy, till that city was taken by the Arabs, and its famous library destroyed (A. D. 642,) which served as fuel for six months to heat the baths of Alexandria.

But the Arabs, in less than a century after they had burnt the library, and dispersed the learned men of Alexandria, began to have a taste for literature, and lamented the loss of what their fathers had destroyed.

They now collected the manuscripts which had escaped the flames, and their barbarity; when Bagdad, their capital city, in the reign of Haroun al Raschid, became the seat of learning, as Alexandria had been under the Ptolemies.

That branch of mathematics, called ALGEBRA, in which numbers and quantities are represented by signs and symbols, commonly by letters, was derived from the Arabs, who are supposed to have borrowed it from the Persians, and they from the Indians. As also the numerical characters or figures; namely, 1, 2, 3, 4, 5, 6, 7, 8, 9, and the 0, a *cypher*, or *Zero.*

Among the most celebrated characters of the middle, or dark ages, were BEDE, his scholar ALCUIN, and Roger Bacon; all natives of England. To their great learning, they joined the knowledge of astronomy, which was very considerable for the age in which they lived.

In the fifteenth century two events happened which changed the face both of literature and science: the invention of printing, about the year 1440; and the taking of Constantinople by the Turks, in 1453.

The learned of that city having escaped from the cruelty of the victors, fled into Italy, and introduced into that country a taste for classical literature, which was greatly promoted by the munificence of the Emperor FREDERIC III.; Pope NICHOLAS V.; and particularly of COSMO DE' MEDICI; who justly merited the name of "FATHER OF HIS COUNTRY," and "PATRON OF THE MUSES."

Among the most celebrated of the modern astronomers were NICOLAS COPERNICUS, the restorer of the Pythagorean doctrine, and the author of the rational, or true system of astronomy, now universally received under the title of the "COPERNICAN SYSTEM:" he was born in Thorn, in Prussia, in 1473; also TYCHO BRAHE, KEPLER, GALILEO, DESCARTES, the great SIR ISAAC NEWTON, and Dr. HERSCHEL.

Copernicus established the rotation of the earth round its axis, which is the cause of day and night, and its motion round the sun, which is the cause of the variety of the seasons. The doctrine of Copernicus, however, was not generally adopted; as the most eminent philosophers of Europe still adhered to old opinions, as those of Ptolemy, and others of the ancients.

The science of astronomy was greatly enriched by Tycho Brahe, a noble Dane, who was born in 1546. He adopted neither the system of Ptolemy, nor that of Copernicus. He supposed the earth to remain at rest, and the sun and moon to move round it, but all the other planets to move round the sun. This opinion, however, had but few followers.

Contemporary with Tycho was the celebrated KEPLER, who was born at Weil, near Wirtemburg, in 1571. Kepler was considered as one of the greatest philosophers that ever lived; and by some is regarded as the discoverer of the "*New System of the World.*" He was an assistant to Tycho Brahe.

Kepler united OPTICS with astronomy, and thus made many important discoveries. He was the first who discovered that the planets move not in a circle, but in an ellipse; and that, although they move sometimes faster, and sometimes slower, yet they describe equal areas in equal times. It was from the principles laid down by Kepler, that Sir Isaac founded many of his discoveries.

Contemporary with Kepler was Galileo, who was born at Pisa, in Italy, in 1564. Galileo was illustrious for his improvements in mechanics, for his explanation of the effects of gravity, and for the invention, or at least the improvement, of telescopes. the use of which opened to him a wide field of wonders.

He now observed with astonishment the increased magnitude and splendour of the planets and their satellites, formerly invisible; which afforded additional proofs of the truth of the

Copernican system; particularly in discovering the satellites of Jupiter, and the phases of Venus. He also discovered an innumerable number of stars, which the naked eye hitherto never could discern.

Up to this period, the system of Copernicus had gained but few converts, and the greater part of the professors and learned men of Europe still supported the old doctrine. The Copernican system was first publicly defended in England by Dr. Wilkins, in 1660: in France by Gassendi, who published many valuable works on philosophy. He was born in 1592, the year that Columbus discovered America, and died in 1655.

DESCARTES, a celebrated philosopher, was born at La Haye, in France, in 1596. He early distinguished himself by his knowledge of mathematics. His notions of astronomy were very similar to those of Copernicus.

But of all the philosophers, the most celebrated was Sir Isaac Newton, who was born at Woolstrope, in the county of Lincoln, on Christmas-day, in 1642. No man ever contributed more to enlarge the boundaries of science than Sir Isaac Newton.

The science of astronomy has been also greatly indebted to Dr. Herschel, who, by augmenting the powers of telescopes beyond the most sanguine expectations, opened a scene of investigation altogether unlooked for.

By this indefatigable observer, we were made acquainted with a new primary planet belonging to our system, called Herschel, or Urănus, which he discovered on the 18th of March, 1781; and which being twice the distance of Saturn from the sun, has doubled the bounds formerly assigned to the "SOLAR SYSTEM."

QUESTIONS FOR EXAMINATION.

What is astronomy? — By whom was it first cultivated? — Who was Thales, and for what distinguished? — Pythagoras? what are his doctrines? — Who was Ptolemy, and for what noted? —By whom and when was the Alexandrian library destroyed? — For what were the Arabs noted? — What were their chief discoveries? — Bagdad? — From whom did the Europeans obtain a knowledge of Algebra, and of the numerical figures? — Who were among the most celebrated characters of the middle ages; and of what country were they natives?—What great events happened in the fifteenth century; and what was the result? — Who were among the most celebrated of the modern astronomers; and of what countries were they natives; and when born?— And for what were they severally distinguished?

DEFINITIONS EXPLAINED.

1. The heavenly bodies are either FIXED STARS or PLANETS.

2. The fixed stars always remain in the same relative position with respect to each other; but the planets are continually changing their places, both with regard to the fixed stars, and to themselves also.

3. The ECLIPTIC is an imaginary great circle in the heavens, which the sun appears to describe in the course of a year.

4. The ECLIPTIC runs along the middle of a certain tract in the heavens called the ZODIAC.

5. Within the ZODIAC the planets are always found.

6. The " SOLAR SYSTEM" consists of the sun as a " centre, of seven primary planets and eighteen satellites," or secondary planets, besides four newly discovered small bodies, called by Dr. Herschel " *asteroids*."

7. The MOON is a secondary planet moving round the earth.

8. The moon and the sun are on the meridian at the same time, every new moon.

9. All the planets move in orbits that are nearly circular, but which are really elliptical, having the sun in one focus.

10. They are preserved in their orbits by the power of attraction, and the centrifugal force, which exactly balance each other.

11. The earth is a spherical body, the diameter of which is nearly 8000 miles long. It is not a perfect sphere, but a spheroid, the diameter from pole to pole being 38 miles shorter than that at the equator.

12. The earth turns on an IMAGINARY AXIS once in 24 hours, thereby producing to its inhabitants a constant succession of day and night.

13. The axis of the earth is inclined about 23½° from the perpendicular.

14. The diurnal motion of the earth, which cannot be made sensible to those who live upon it, leads the uninformed to believe that the heavenly bodies rise every day in the east and set in the west.

15. The people on the equator travel by the diurnal motion of the earth at the rate of 1000 miles in an hour.

16. The *sensible horizon* differs from the *rational horizon* in this, that the former is seen from the surface of the earth, and the latter is supposed to be viewed from its centre.

17. The heavens are in every part adorned with stars, but those above the horizon in the day cannot be seen owing to the stronger light of the sun.

18. The earth has an annual motion round the sun, which it performs in about 365¼ days.

19. The annual motion of the earth, and the inclined position of its axis, are the causes of the different lengths of the days and nights, and of the different seasons.

20. Owing to the elliptical orbit of the earth, we are 3,000,000 of miles nearer to the sun in winter than in summer.

21. The heat of summer depends on the greater perpendicularity of the rays of the sun, and upon the time which he is above the horizon.

22. The hottest part of the day is two or more hours after noon; and the hottest part of the summer is a month or two after the longest day.

23. The rotation of the earth; that is, the space of time which any particular meridian takes in revolving from a fixed star to that star again is 23 hours 56 minutes and 4 seconds. This is called the *sidereal* day.

24. The *solar* day is the time which any meridian of the earth takes in revolving from the sun to the sun again: this is about 24 hours, a little more or less.

25. JULIUS CÆSAR divided the year into 365 days and a quarter, making one year in four to contain 366 days, and the other three 365.

26. The length of the year being only $365d\ 5h\ 48'\ 49''$ occasions the error of a whole day in 130 years.

27. The *Julian year* continued in general use till 1582, when the error, which amounted to 10 days, was corrected by POPE GREGORY. Hence the "*New Style*," which was not adopted in England till the year 1752.

28. Till this period, the year began in England on the 25th of March, but since, the commencement of each year has been on January 1.*

29. The *periodical month*, or the time which the moon takes in revolving from one point of the heavens to another, consists of 27*d* 7*h* 43′.

30. The *synodical month*, or the time passed from new moon to new moon is 29*d* 12*h* 44′.

31. The moon shines with a light borrowed from the sun.

32. The diameter of the moon is nearly 2200 miles in length, and she is 240,000 miles distant from the earth.

33. At change or new moon, that body is between the earth and sun.

34. At full moon, the earth is between the sun and moon.

35. The length of a day and night in the moon is equal to rather more than twenty-nine and a half of our days: the length of her year, which is measured by her journey round the sun, is equal to that of ours.

36. One hemisphere of the moon is never in darkness: to the other there is a fortnight's light and darkness by turns.

37. The earth may be regarded as a satellite to the moon, and will appear to the inhabitants of that body, subject to all the changes which the moon undergoes.

38 All the planets probably revolve about an imaginary axis, in various periods of time, which constitute their day and night.

39. In every planet, its revolution about the sun forms its year.

40. In most of the planets the axis is inclined to the orbit, which occasions the diversity of seasons.

41. *Eclipses of the sun* are occasioned by the moon coming between the earth and the sun, and thus hiding its disc from our view.

42. *Eclipses of the moon* are owing to the shadow of the earth projected by the sun falling upon the moon.

43. The eclipses of the other satellites are caused by their coming into the shadows of their respective primaries.

44. The TIDES are owing to the effect of the attraction of the moon and sun upon the waters of the sea.

45. When the sun and moon act together they occasion *spring* tides: when they counteract each other's attraction, *neap* tides take place.

46. The moon in general rises about three quarters of an hour later every day than on the one preceding: but about the time of harvest, and some days before and after full moon, it rises several nights together, within a few minutes of the same time. This is called the "HARVEST-MOON."

47. *Mercury* is the planet nearest the sun.

48. MERCURY and VENUS are called inferior planets, because they revolve in orbits included within that of the earth. They are called attendants upon the sun because they are always so near that body, as never to be seen on the one side of the heavens when he is on the other.

49. Mercury revolves round the sun at the distance of 37 millions of miles, and his year is about 88 of our days. The heat which this planet enjoys is seven times greater than that experienced by the inhabitants of the earth.

50. Venus is 49 millions of miles from the sun, and her year is about 224¼ of our days.

51. The diameter of Venus is 7700 miles in length. She turns about her

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* Hence, in many books, we find such dates as this, Feb. 2, 1759-60. Because the months of January, February, and part of March were, according to the old style, in 1759; but according to the new regulations they were in 1760.

axis in 23 hours and 20 minutes. The light and heat experienced by this planet are about twice as great as those which we enjoy.

52. VENUS is an evening star when she is east of the sun, and a morning star while she is seen west of him.

53. The *transit* of Venus happens twice in about 120 years.

54. From the transit of Venus the distances of the other planets have been demonstrated.

55. MARS is 144 millions of miles from the sun: the length of his year is 687 of our days; and the rotation on his axis is performed in 24 hours 39 minutes.

56. The diameter of Mars is only 4189 miles, and he enjoys about half as much light and heat as we experience.

57. The diameter of Jupiter is 90,000 miles, and his distance from the sun is estimated at 490 millions of miles.

58. The year of Jupiter is equal to nearly 12 of ours, and a day and night in that planet are equal to ten hours. The inhabitants of Jupiter do not enjoy more than a twenty-fifth part as much heat and light as we do on the earth.

59. The equatorial diameter of Jupiter is 6000 miles greater than the polar diameter.

60. There is no inclination of the axis of Jupiter, and of course no variety of seasons.

61. JUPITER has *four* satellites, subject to be eclipsed like our moons. From these eclipses, it has been found that rays of light come from the sun to the earth in *eight minutes;* of course, light travels at the rate of 12 millions of miles in a minute.

62. The diameter of Saturn is nearly 30 thousand miles in length; his distance from the sun is more than 900 millions of miles, and his year is about equal to thirty of ours.

63. Saturn enjoys 90 times less light and heat than are experienced by the earth; nevertheless, the light of the sun at Saturn is equal to more than 500 times that which we enjoy from the full moon.

64. Saturn is attended by *seven* moons; and is encompassed by two broad rings, which are probably useful in reflecting light from the sun on the body of the planet.

65. Saturn's day and night is about 12¼ hours, and his equatorial diameter is longer than his polar diameter in the proportion of 11 to 10.

66. The diameter of Herschel is nearly 35 thousand miles in length, and his distance from the sun is estimated at 1800 millions of miles.

67. The year of Herschel is equal to 82 of our years. He has six satellites;—the light and heat enjoyed by this planet from the sun are more than 360 times less than we have; the light is, however, equal to about 248 of our full moons.

68. COMETS are a species of planets moving in very eccentric orbits; sometimes they are very near the sun, at other times at immense distances from him.

69. All the heavenly bodies move faster or slower, in proportion as they are nearer to, or more distant from their centre of motion.

70. Comets are frequently accompanied by a luminous train, called the tail.

71. The SUN has a rotation on his axis from west to east, which he completes in about 25 days, which is two days less than his apparent revolution.

72. The sun's diameter is equal to 100 diameters of the earth, his bulk is accordingly about a million of times greater than that of the earth: but the density of the matter of which the sun is composed, is four times less than the density of our globe.

73. The FIXED STARS are probably suns at immense distances from us and from each other: and our sun is only a fixed star much nearer to us, forming the centre of our system.

74. So distant is the nearest fixed star from us, that a ray, which travels at the rate of 12 millions of miles in a minute, would be three years in passing from it to us.

HYDROSTATICS.

FIRST CONVERSATION.

INTRODUCTION.

FATHER — CHARLES — EMMA.

Father. In pursuing our study of Natural and Experimental Philosophy, we shall now proceed with that branch of science which is called "HYDROSTATICS."

Em. That is a difficult word, Papa. What are we to understand by it?

Fa. Almost all the technical terms made use of in science are either Greek, or derived from the Greek language, as I have previously told you. The word *hydrostatics* is formed of two Greek words *hydor* (ὑδωρ) "water," and *statics* from *stao* (σταω) "I stand," and is the science which considers the *weight* or *equilibrium of bodies.* But Hydrostatics, as a branch of Natural Philosophy, treats of the nature, pressure, motion, and equilibrium of FLUIDS in general, and likewise of the methods of weighing SOLIDS in them.

Ch. Is this an important part of knowledge?

Fa. Taken in this extensive sense, it yields to none, as to real importance; and as to interest, the experiments I shall show you are curious and highly amusing.

Em. Shall we be able to repeat them ourselves?

Fa. Yes, most of them, provided you are very careful in using the instruments, almost all of which are made of glass. I ought to tell you that many writers divide this subject into two distinct parts, viz. *Hydrostatics* and *Hydraulics;* the latter relating particularly to the motion of water through pipes, conduits, &c., the laws by which it is regulated, and the effects it produces: the word *Hydraulic* is derived from the Greek *hydor* (ὑδωρ) "water," and *aulos* (αὐλος) "a pipe."

Here, however, I shall pay no regard to this distinction, but describe, under the general title of Hydrostatics, the pro-

perties of all fluids, and principally those of water; explaining, as we go on, the motions of it, whether in pipes, pumps, or syphons, and the engines of different kinds, fountains, &c., in connexion with it. Do you know what a fluid is?

Ch. I know certainly how to distinguish a fluid from a solid: water and wine are fluids; but why they are so called, I cannot tell.

Fa. A fluid is generally defined to be a body; the parts of which readily, without any sensible resistance, yield to any impression, and in yielding are easily moved amongst each other.

Em. But this definition does not notice the wetting of other bodies brought into contact with a fluid. If I put my fingers into water or milk, a part of it adheres to them, and they are said to be wet.

Fa. Every accurate definition must mark the qualities of all the individual things defined by it. There are many fluids which have not the property of wetting the hand when plunged into them. The air we breathe is a fluid, the parts of which yield to the least pressure; but it does not adhere to the bodies surrounded by it, like water.

Em. Air, however, is so different from water, that, in this respect, the two will scarcely admit of comparison.

Ch. I have sometimes dipped my finger into a cup of quicksilver; but none of the fluid adhered to it.

Fa. Of course: and hence you will find that Natural Philosophy distinguishes between fluids and liquids. Air, quicksilver, and melted metals, are *fluids*, but not *liquids:* while water, milk, beer, wine, oil, spirits, &c., are both fluids and liquids.

Ch. Are we then to understand, that liquids are known by the property of adhering to different substances which are immersed in them?

Fa. This description will not always hold good; for, although mercury will not stick to your finger if plunged into a cup of it, yet it will adhere to many metals, such as tin, gold, &c.: and therefore you will remember that the distinction between liquids and fluids is used more on account of common convenience than philosophical accuracy.

Em. You said, I believe, Papa, that a fluid is a body whose parts yield to the smallest force impressed.

Fa. That is the definition of a perfect fluid; and the less force that is required to move the parts of a fluid, the more perfect is that fluid.

Ch. But how do people reason respecting the particles of which fluids are composed? Have they ever seen them?

Fa. Philosophers imagine they must be exceedingly small, because, with their best glasses, they have never been able to discern them. And they contend that these particles must be round and smooth, as they are so easily moved among and over one another. If they are round, there must be vacant spaces left between them.

Em. How is that, Papa?

Fa. Suppose a number of cannon balls were placed in a large tub, or any other vessel, so as to fill it up even with the edge: although the vessel would contain no more of these large balls, yet it would hold in the vacant spaces a great many smaller shot; and between these, others still smaller might be introduced: and when the vessel would contain no more small shot, a great quantity of sand might be shaken in, between the pores of which, water or other fluids would readily insinuate themselves.

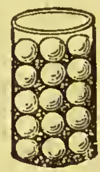

Fig. 1.

Take a phial with some rain water: mark very accurately the height at which the water stands in the bottle: and then introduce a small quantity of salt, which, when completely dissolved, you will find has not in the least increased the bulk of the water. When the salt is taken up, sugar may also be dissolved in the same water, without making any addition to its bulk.

Em. Are we then to infer that the particles of salt are smaller than those of water, and lie between them, as the small shot lie between the cannon balls; and that the particles of sugar are finer than those of salt, and like the sand among the shot, will insinuate themselves into vacuities too small for the admission of the salt?

Fa. I think the experiment fairly leads to that conclusion. Another fact respecting the particles of fluids, deserving your notice, is, that they are exceedingly hard, and almost incapable of compression.

Ch. What do you mean, Papa, by compression?

Fa. I mean the act of squeezing anything in order that its

parts may be brought nearer together. Almost all substances with which we are acquainted may, by means of pressure, be reduced into a smaller space than they naturally occupy. But water, oil, spirit, quicksilver, &c., cannot, by any pressure of which human art or power is capable, be reduced into a space *sensibly* less than they naturally possess.

Em. Has the trial ever been made?

Fa. Yes; and by some of the ablest philosophers that ever lived: they have found that water will penetrate through the pores even of gold, rather than suffer compression into a smaller space.

Ch. How was that tried?

Fa. At Florence, a celebrated city in Italy, a globe made of gold was filled with water, and then closed so accurately that none of it could escape. The globe was then put into a press, and a little flattened at the sides: the consequence of which was, that the water came through the fine pores of the golden globe, and stood upon its surface, like drops of dew.

Ch. Would not the globe, then, contain as much, after its sides were bent in, as it did before?

Fa. It would not: and as the water forced its way through the gold rather than suffer itself to be brought into a smaller space than it naturally occupied, it was concluded, at that time, that water was incompressible. Later experiments have, however, shown that those fluids which were esteemed incompressible, are capable of compression in a very small degree, (to the extent, perhaps, of one part in twenty thousand.)

Em. Is it on this account you conclude that the particles are very hard?

Fa. Undoubtedly: for if they were not so, you can easily conceive that, since there are vacuities between them, as we have shown, and as are represented in fig. 1, they must by very great pressure be brought closer together, and would evidently occupy a less space, which is contrary to fact.

Ch. Then I suppose water may be said to be incompressible?

Fa. Water, oil, spirits, &c., are said to be incompressible, not because they are absolutely so, but because their compressibility is so very small as to make no sensible difference in calculations relative to the several properties of those fluids.

Mr. Canton discovered the compressibility of water in the year 1761; and he says that, from repeated trials, he found that water will expand and rise in a tube by removing the weight of the atmosphere about one part in 21,740, and will be as much compressed under the weight of an additional atmosphere.*

These principles of compressibility and incompressibility have given rise to a division of fluids into two kinds—viz., *elastic* and *non-elastic.* The mechanical properties of elastic fluids, such as air and the different gases, constitute the science of *Pneumatics*, which I hope by and bye fully to explain to you: on the other hand, the non-elastic fluids, such as water, spirit, &c., constitute our present subjects of *Hydrostatics* and *Hydraulics.*

Ch. But you have just said, Papa, that they were compressible in some very small degree: how therefore can they be called *non-elastic?*

Fa. You must bear in mind that the terms elastic and non-elastic are employed not in the absolute sense, but in a relative sense; for water, spirits, and all other fluids of that class are, to a certain extent, compressible and elastic; but they resist compression with so very great a force, that the conclusions obtained on the supposition of their being entirely incompressible are free from any sensible error, except when the pressure is extraordinarily great; whence has arisen the twofold division of fluids into elastic and non-elastic.

You have had now a general statement of what is meant by fluids. Do you understand the explanation?

Ch. Yes: but I have imagined that to constitute a *perfect* or *philosophical* fluid, if I may so term it, which does not exist in nature, it is necessary that the parts be not held together by mutual attractions, nor obstructed in their motions by friction or attraction.

Fa. Nevertheless, do you not admit it to be a fluid?

Ch. That it is fluid in a certain degree, there can be no doubt; but if fluids consist of small particles, how is it known that those particles are spherical?

Fa. On that subject there are many opinions; but I conceive it to be of little consequence, as the original cause of

* See Phil. Trans. Vol. LII.

fluidity does not appear to consist in the figure of the particles, but in their want of cohesion. However, as this belongs more to Chemistry, we will, if you please, cease to consider it at present. Newton's definition of a fluid, "that it is a body, the smallest portion of which is put into motion by the slightest force," is nothing more than an expression of the physical fact. Grains of sand are more easily moved than the parts of many viscous fluids; yet sand is not a fluid. Fluidity is the intermediate condition between the solid and the aëriform, and depends principally on the quantity of space in which the atoms of the body are involved. A fluid is elementary matter intermixed with such a proportion of space as leaves a pressure internally a fraction less than externally. As with solids, external pressure is much the greater, and with gases, the internal is equal to the external pressure, so, in fluids, external over internal pressure is of that slight degree which permits mobility of the elementary atoms, in consequence also of the medium between them preventing their remaining in immediate contact.

QUESTIONS FOR EXAMINATION.

From what is the word *hydrostatics* derived? — As a branch of science, of what does it treat? — Into what parts is it divided?—To what does the science of hydraulics relate? — How is a fluid defined? — How do you distinguish between fluids and liquids? — Upon what does the perfection of a fluid depend? — Of what kind of particles are fluids supposed to be formed? — What are the reasons assigned why the particles of fluids should be spherical? — Can anything be added to a fluid without increasing its bulk? — Give an instance in point: how do you account for this? — Are fluids compressible? — Who made the experiment with water, and what was the result? — Have any later experiments proved that fluids are capable of compression?—What reason is advanced to prove that the particles of water are hard?

CONVERSATION II.

OF THE WEIGHT AND PRESSURE OF FLUIDS.

Father. In our last conversation, my dear children, we considered the nature of the component parts of fluids. I must now tell you that these parts or particles act, with respect to their weight or pressure, independently of each other.

Em. Will you explain what you mean by this?

Fa. You recollect that, by the attraction of cohesion,* the parts of all solid substances are kept together, and press into one common mass. If I cut off a part of this wooden ruler, the rest will remain in precisely the same situation as before; but if I take some water out of the middle of a vessel, the remainder flows instantly into the place from whence that portion was taken, so as to bring the surface of the whole mass to a level.

Ch. Have the particles of water no attractive influence upon each other?

Fa. Yes, in a slight degree. The globules of dew† on cabbage plants prove that the particles of water have greater attraction towards each other than they have to the leaf on which they stand. Nevertheless, this attraction is very small; and you can easily conceive that, if the particles are round, they will touch each other in very few parts, and slide with the smallest pressure. If a few of the little globules were taken out of a vessel, such as that represented by fig. 1, it is evident that the surrounding ones would fall into their place if the fluids are of equal density, for a light fluid will float on the surface of a heavier one, as oil, or spirit, on water; and air, likewise, will rise to the surface of any fluid, from being forced up by the greater gravity of the surrounding fluid. Upon the principle above alluded to, the surface of every fluid, when at rest, is horizontal or level.

Ch. Is it upon the same principle that water-levels are constructed?

Fa. It is. The most simple kind of water-level is a long wooden trough, which being filled to a certain height with water, its surface shows the level of the place on which it stands.

Ch. I did not allude to this kind of level, but to those smaller instruments constructed of glass tubes.

Fa These are, more properly speaking, air-levels. They are thus constructed: D is a glass tube fixed into L, a socket made generally of brass. The glass is filled with water, or some other fluid, in which is enclosed a single bubble of air. When this bubble fixes itself at the mark *a*, made exactly in

Fig. 2.

* See Mechanics. Conversation III. p. 13.
† See Mechanics. Conversation IV. p. 19.

the middle of the tube, the place on which the instrument stands is perfectly level. When it is not level, the bubble will quit the central mark and rise to the higher end.

Ch. What is a spirit-level, Papa?

Fa. A spirit-level is similar to a water-level, but has the tube filled with spirit of wine by reason of its greater mobility, and freedom from congelation by freezing.

Em. What is the use of these levels?

Fa. They are fixed to a variety of philosophical instruments, such as quadrants and telescopes for surveying the heavens, and theodolites for taking the level of any part of the earth: their accuracy depends considerably on the regularity of the internal surfaces of the tube, which, if made of glass, are sometimes ground to give them a regular cylindrical or spindle form, with a slight spherical curvature; for greater exactness, the tube and bubble should be of considerable length; and the larger the bubble the more freely it moves, and in consequence is far more susceptible of the least inclination; in fact, they can be made to indicate a deviation from the true horizontal line as small as that of a single second of angular measure. They are also useful in the more common occurrences of life. A single instance will show their value. Clocks will not keep true time unless they stand very upright: now, by means of one of these levels, you may easily ascertain whether the bracket upon which the clock in the passage stands is level.

Em. I remember, however, that when Mr. Timely brought home your clock, he tried if the bracket was even by means of one of Charles's marbles. How could he know by that?

Fa. The marble, being round, touched the board in a point only; consequently the line of direction* could not fall through that point; but the marble would roll if the bracket were not level: therefore, when the marble was placed in two or more different parts of the board, and did not move to one side or the other, he might safely conclude that it was level.

Ch. Then the water-level and the rolling of the marble depend on the same principle.

Fa. Yes; upon the supposition that the particles of water are round. The water, or spirit level, will, however, be more accurate, because we may imagine that the parts of which a

* See Mechanics. Conversation IX. p. 35.

fluid is composed are perfectly round, and therefore, as may be geometrically proved, they will touch only in an infinitely small point: whereas marbles, made by human contrivance, touch in many such points. From these observations you must have remarked that solid bodies gravitate in masses, the powerful cohesion of their particles making them operate altogether, whereas every particle of a fluid may be considered as a separate mass gravitating independently of its fellow; wherefore the resistance presented by a fluid is considerably less than that offered by a solid.

We now come to another very curious principle in this branch of science, derived from the above properties—viz., *that fluids press equally in all directions.* All bodies, both fluid and solid, press downwards, you are aware, by the force of gravitation; but fluids of all kinds exert likewise not only a pressure upwards, but also a pressure sideways, which equals the pressure downwards; in consequence of this equable pressure, every particle in the fluid remains at rest.

Em. Can you show us, Papa, any experiments in proof of this?

Fa. Yes: *a, b, c,* is a bent glass tube. With a small glass funnel pour into the mouth at *a* a quantity of sand. You will find that, when the lower part is filled, whatever is poured in afterwards, will stand in the side of the tube *a b,* and not rise in the other side, *b c.*

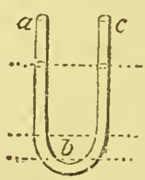

Fig. 3.


Fig. 4.

Ch. The reason of this is, that by the attraction of gravitation all bodies have a tendency to the earth;* that is, in this case, to the lowest part of the tube: but if the sand ascended in the side *b c,* its motion would be directly the reverse of this principle.

Fa. You mean to say that the pressure would be upwards, or *from* the centre of the earth.

Ch. It certainly would.

Fa. Well, we will pour away the sand, and put water in its place. What do you say to this?

Em. The water is level in both sides of the tube.

Fa. This, therefore, proves that, with respect to fluids, there is a pressure upwards, at the point *b,* as well as down-

* See Mechanics. Conversation V. p. 21.

wards. So, if you pour water into a tea-pot, or coffee-pot, the water rises in the spout to the same level with that in the pot, because the particles continuing to descend upon those at the bottom of the pot, the latter yield to their pressure, and as they cannot descend lower, they make way in an upward direction up the spout. I will show you another experiment.

A B is a large tube or jar, having a flat bottom: *a b* is a smaller tube open at both ends. While I fill the jar with water, I take care to hold the small tube so close to the bottom of the jar as to prevent any water from getting into the tube. I then raise it a little, and you see it is instantly filled with water from the jar.

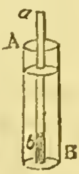

Fig. 5.

Ch. It is: and the water in the jar and the tube take the same level.

Fa. The latter, you saw, was filled by means of the pressure upwards, contrary to its natural gravity.

Take out the tube. Now, the water having escaped, the tube is filled with air. Stop the upper end, *a*, with a cork, and plunge it into the jar, the water will only rise as high as *b*.

Em. What is the reason of this, Papa?

Fa. The air with which the tube was filled is a body, and, unless the water were first to force it out of the tube, it cannot take its place. While this ink-stand remains here, you are not able to put any other body in the same part of space.

Ch. If air be a substance, and the tube is filled with it, how can any water make its way into the tube?

Fa. That is a very proper question. Air, though a substance, and, as we have already observed, a fluid too, differs from water in this respect, that it is easily compressible; that is, the air, which by the natural pressure of the surrounding atmosphere, fills the tube, may, by the additional upward pressure of the water, be reduced into a smaller space, as *a b*. Another experiment will illustrate the difference between compressible and incompressible fluids.

Fill the tube, which has still a cork in one end, with some coloured spirit of wine: over the other end place a piece of pasteboard, held close to the tube, to prevent any of the liquor from escaping: in this way introduce the tube into a vessel of water, keeping it perpendicular all the time. You may now

take away the pasteboard, and force the tube to any depth; but the spirit is not like the air; it cannot in this manner be reduced into a space smaller than it originally occupied.

Em. Why did not the spirit of wine run out of the tube into the water?

Fa. Because spirit is lighter than water; and it is a general principle that the lighter fluid always rises to the top.

Take a thin piece of horn or pasteboard, and, while you hold it by the edges, let your brother put a pound weight upon it. What is the result?

Em. It is almost bent, so that I can scarcely hold it.

Fa. Introduce it now into a vessel of water, at the depth of twelve or fifteen inches, and bring it parallel with the surface. In this position it sustains many pounds weight of water.

Ch. Nevertheless, it is not bent in the least.

Fa. Because the upward pressure against the lower surface of the horn is exactly equal to the pressure downward; or, which is the same thing, it is equal to the weight of the water which it sustains on the upper surface.

You may vary these experiments by yourselves till we meet again; when I hope to resume the subject.

QUESTIONS FOR EXAMINATION.

How do the particles of fluids act?— Give an instance to illustrate this.— Do the particles of water attract each other? — Why do the globules of dew on plants run off without seeming to wet them? — Explain the structure and uses of the level, see fig. 2. — To what purposes are levels applied?—In what directions do fluids press? — Can you, by fig. 3, show how it is that fluids press upwards and sideways as well as downwards? — Is air easily compressible?— Can you exhibit this by an experiment? — Of two fluids of different densities, which will be uppermost? — Can you show by means of pasteboard, or horn, that the upper pressure of fluids is equal to the pressure downwards?

CONVERSATION III.

OF THE WEIGHT AND PRESSURE OF FLUIDS.

Charles. When you were explaining the principle of the Wheel and Axle,* you were kind enough to show me how it was that the difficulty of drawing up a bucket full of water so much increased when it was nearly at the top of the well. I

* See Mechanics. Conversation XVII. p. 69.

have just now found another thing in connexion with that subject beyond my comprehension. When the bucket is filled with water, it sinks to the bottom of the well, or as far as the rope will suffer it; but, in drawing it up through the water, it seems to have little or no weight till it comes to the surface of the water. How is this accounted for?

Fa. I do not wonder that you have noticed that circumstance as singular. It was long believed by the ancients, that water did not gravitate, or had no weight, in water; or, as they used to express it more generally, that fluids "do not gravitate *in proprio loco.*"

Em. I do not understand the meaning of those words.

Fa. I will explain their meaning without translating them, because a mere literal translation would give you a very inadequate idea of what the words are intended to express.

No one ever doubted that water and other fluids had weight when considered by themselves; but it was supposed that they had no weight when immersed in a fluid of the same kind. The fact which your brother has just mentioned, respecting the bucket, was that upon which this doctrine was advanced and maintained.

Em. Does it not weigh anything, then, till it is drawn above the surface?

Fa. You must, my dear girl, have patience, and you shall see how it is. Here is a glass bottle, A, with a stop-cock, B, cemented to it; by means of which the air may be exhausted from the bottle, and prevented from returning into it again. The whole is made sufficiently heavy to sink in the vessel of water, C D.

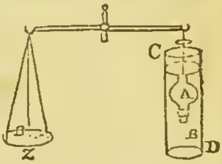

Fig. 6.

The bottle must be weighed in air; that is, in the common method; and supposing it to weigh 12 ounces, let it be put into the situation represented by the figure, and then the weight of the bottle must be again taken, by putting weights into the scale *z*. I now open the stop-cock, while it is under water, and the water immediately rushes in and fills the bottle, which overpowers the weights in the scale: then I put other weights, say 8 ounces, into the scale, to restore the equilibrium between the bottle and scale. It is evident, therefore, that 8 ounces is the weight of the water in the

bottle while weighed under water. Now, fasten the cock, and weigh the bottle in the usual way in the air.

Ch. It weighs something more than 20 ounces.

Fa. That is, 12 ounces for the bottle, and 8 ounces for the water, besides a small allowance to be made for the drops of water that adhere to the outside of the bottle. Does not this experiment prove that the water in the bottle weighed just as much in the jar of water as it weighed in the air?

Em. I think it does.

Fa. Then we are justified in concluding that the water in the bucket, which the bottle may represent, weighed as much, while under water in the well, as it did after it was raised above the surface.

Ch. This fact seems decisive; but the difficulty still remains in my mind; for the weight of the bucket is not felt till it is rising above the surface of the water.

Fa. It may be thus accounted for. Any substance of the same specific gravity with water may be plunged into it, and it will remain, wherever it is placed, either near the bottom, in the middle, or towards the top; consequently it may be moved in any direction by the application of a very small force.

Em. What do you mean by the specific gravity of a body?

Fa. The *specific gravity* of any body is its weight *compared* with that of any other body. Hence it is also called the *comparative* gravity: to say that lead, or iron, or stone, is heavy, and that feathers, or wool, &c., is light, we only speak comparatively, and with respect to substances generally. Wood is light when compared to stone, but heavy when compared to cork, or wool; so earth is heavy when compared to wood, but light when compared to metal, as lead or iron; whence our ideas of weight are very undefined, and some standard is therefore necessary to which the weight of other substances may be referred: the standard fixed upon has been water. Thus, if a cubic inch of water be equal in weight to a cubic inch of any particular kind of wood, the specific or comparative gravities of the water and that wood are equal. But, since a cubic inch of deal is lighter than a cubic inch of water, and the latter is lighter than the same bulk of lead, or brass, we say the specific gravity of the lead, or brass, is greater than that of water, and the specific gravity of water is greater than that of deal.

Ch. The water in the bucket must therefore be of the same specific gravity with that in the well, because it is a part of it.

Fa. And the wooden bucket differs very little in this respect from the water; because, though the wood is lighter, yet the iron of which the hoops and handle are composed is specifically heavier than water; so that the bucket and water are nearly of the same specific gravity with the water in the well, and therefore it is moved very easily through it.

Again, we have already proved that the upward pressure of fluids is equal to the pressure downwards; therefore the pressure at the bottom of the bucket, upwards, being precisely equal to the same force in a contrary direction, the application of a very small force, in addition to the upward pressure, will cause the bucket to ascend.

Em. You account for the easy ascent of the bucket upon the same principle by which you have shown that horn or pasteboard will not be bent, when placed horizontally at any depth in water?

Fa. Yes; and I will show you some other experiments, to prove the effect of the upward pressure.

Take a glass tube, open at both ends, the diameter of which is about the eighth of an inch; fill it with water, and close the top with your thumb: you may now take it out of the water; but it will not empty itself whilst the top is kept closed.

Ch. This is not the upward pressure of water; because the tube was taken out of it.

Fa. You are right: it is the upward pressure of the air, which, while the thumb is kept on the top, is not counterbalanced by any downward pressure; therefore it keeps the water suspended in the tube.

Take this ale-glass; fill it with water, and cover it with a piece of writing-paper; then place your hand evenly over the paper, so as to hold it very tight about the edge of the glass, which you may now invert, and take away your hand without any danger of the water falling out.

Em. Is the water sustained by the upward pressure of the air ?

Fa. The upward pressure of the air against the paper sustains the weight of water, and prevents it from falling.

You have seen the instrument used for tasting beer or wine?

Em. Yes; it is a tin tube, holding about half a pint; into which very small tubes are inserted at the top and bottom.

Fa. The longest of these tubes is put into the hole made for the vent-peg, and then the beer or wine, by drawing out the air from it, is forced into the large part of the tube, and, by putting the thumb or finger on the upper part, the whole instrument may be taken out of the cask, and removed anywhere; for the pressure of the air against the bottom surface of the lower tube keeps the liquor from running out; but, the moment the thumb is taken from the top, the liquor descends by the downward pressure of the air.

Ch. Is it for a similar reason that vent-holes are made in casks?

Fa. It is: for when a cask is full, and perfectly closed, there is no downward pressure, and therefore the air, pressing against the mouth of the cock, keeps the liquor from running out. A hole made at the top of the cask admits the external pressure of the air, by which the liquor is forced out. In large casks of ale or porter, where the demand is not very great, the vent-hole need seldom be used; for a certain portion of the air contained in the liquor escapes, and, being lighter than the beer, ascends to the top, by which a pressure is created without the assistance of the external air. The whole pressure sustained by any definitive portion of the bottom or sides of a vessel depends only on the column of liquid standing on that portion as its base, together with the altitude; the pressure therefore on the bottom of a vessel depends on the magnitude of the bottom and depth of the liquid, and is not at all affected by the form of the sides and of the quantity of liquid in the vessel; but this will be treated of more in our conversation on the Hydrostatic Paradox.

Ch. Do not these principles have some influence, Papa, on the construction of boats and ships?

Fa. Yes: particularly in the matter of stowage: for a substance placed on a fluid specifically heavier than itself will sink so far that the weight of the fluid displaced is equal to the whole weight of the body: it is upon this principle that the tonnage of barges on our canals is ascertained, and the toll calculated.

QUESTIONS FOR EXAMINATION.

Why, in drawing up a bucket from a deep well, does it appear to have little or no weight while it ascends through the water?—On this subject explain the experiment illustrated by fig. 6.—How is the fact accounted for?—What is meant by the specific gravity of a body?—Is the pressure of the water upward against the bottom of the bucket equal to the same force in the contrary direction?—Why will not the water in a glass tube of a small bore, open at both ends, run out, provided the upper part be kept closed?—Explain the experiment of the ale-glass filled with water.—How do you account for the operation of the instrument for tasting wine or beer?—Why are vent-holes made in casks?

CONVERSATION IV.

OF THE LATERAL PRESSURE OF FLUIDS.

Father. It is time now to advance another step in this science, and to show you that the *lateral*, or *side* pressure, is equal to the perpendicular or vertical pressure.

Em. If the upward pressure is equal to the downward, and the side pressure is also equal to it, then the pressure is equal in all directions.

Fa. Undoubtedly. Though the side direction may be varied in many ways, yet there are only the upward, downward, and lateral directions of pressure. The two former we have shown, are equal. That the side pressure is equal to the vertical pressure is demonstrable by a very easy experiment.

Fig. 7.

A B is a vessel filled with water, having two equal orifices or holes, *a*, *b*, bored with the same tool, one at the side, and the other in the bottom: if these holes are opened at the same instant, and the water suffered to run into two glasses, it will be found that, at the end of a given time, they will have discharged equal quantities of water; which is a clear proof that the water presses sideways as forcibly as it does downwards; and it is equally clear that without lateral pressure, water, or other fluids, would not flow from any opening in the side of a vessel: sand will not flow from such an opening, because it possesses no lateral pressure among its particles, or at least so little as to make no very palpable exhibition of it.

Ch. Are we therefore to take it as a general principle, that fluids press in every possible direction?

Fa. This, I think, our experiments have proved: but you must not forget that it is only true upon the supposition that *the perpendicular heights are equal;* for, in the last experiment, if the hole *b* had been bored an inch or two higher in the side of the vessel, as at *c*, the quantity of water running out at *a* would have been greater than that at *c;* and much greater would it have been if the hole had been bored at four or five inches above the bottom of the vessel.

This subject of pressure may be farther illustrated. At the bottom of this tube, N *y*, open at both ends, I have tied a piece of bladder, and have poured in water till it stands at the mark *x*. Owing to the pressure of the water, the bladder is convex; that is, bent outwards. Dip it into the jar (fig. 5) the bladder is still convex: thrust it gently down, the surface of the water in the tube is now even with that in the jar.

Fig. 8.

Em. It is; and the bladder at the bottom is become flat.

Fa. The perpendicular depths being equal, the pressure upward is equal to that downwards, and the water in the tube is exactly balanced by the water in the jar. Let the tube be thrust deeper into the water.

Ch. Now the bladder is bent upwards.

Fa. The upward pressure is estimated by the perpendicular depth of the water in the jar, measured from the surface to the bottom of the tube; but the pressure downwards must be estimated by the perpendicular height of the water in the tube, which being less than the former, the pressure upwards in the same proportion overcomes that downwards, and forces up the bladder into the position as you see it. This and the following experiment demonstrate the upward pressure of fluids.

Dip an open end of a tube, having a very narrow bore, into a vessel of quicksilver; then, stopping the upper orifice with the finger, lift up the tube out of the vessel, and you will see a column of quicksilver hanging at the lower end, which, when dipped in water lower than 14 times its own length, will, upon removing the finger, be pressed upwards into the tube.

Em. Why do you fix upon 14 times the depth?

Fa. Because quicksilver is 14 times heavier than water. Upon this principle of the upward pressure, lead, or any other metal, may be made to swim in water. A B is a vessel of water, and *a b* is a glass tube open throughout; *d* is a string by which a flat piece of lead, *x*, may be held fast to the bottom of the tube. To prevent the water from getting in between the lead and the glass, a piece of wet leather is first put over the lead.

Fig. 9.

In this situation, let the tube be immersed in the vessel of water, and if it be plunged to the depth of about eleven times the thickness of the lead before the string be let go, the lead will not fall from the tube, but be kept adhering to it by the upward pressure below it.

Em. Is lead 11 times heavier than water?

Fa. It is between 11 and 12 times heavier; and therefore, to make the experiment sure, the tube should be plunged somewhat deeper than 11 times the thickness of the lead.

Ch. Is it not owing to the wet leather, rather than to the upward pressure, that the lead adheres to the tube?

Fa. If that be the case, it will remain fixed if drawn up the tube an inch or two higher. I will try it.

Em. It has fallen off.

Fa. Because, when the tube was raised, the upward pressure was diminished so much as to become too small to balance the weight of the lead: but if the adhering together of the lead and tube had been caused by the leather, there would be no reason why it should not operate the same at six or nine times the depth of the lead's thickness as well as at 11 or 12 times that thickness.

The lateral pressure, you must now perceive, arises from the downward pressure, or weight of the superincumbent liquid; so that the lower the opening is made in the side of a vessel, the greater will be the velocity of the water rushing out, nor is it at all influenced by the horizontal dimensions of the vessel containing the liquid, but the depth only; for as every particle acts independently of the rest, it is only the column of particles immediately above the opening that weigh down and press out the liquid. What now have you understood as to the gravity of fluids in these Conversations?

Ch. I understand that they all gravitate upon a bottom of

a cylindrical vessel in which they are contained, in the same manner as solids gravitate; that is, in proportion to the quantity of matter. I have learned also that in every part of the fluid there is a pressure, equal to gravitation, in all directions: wherefore, since every part of the fluid is acted upon in all manner of directions by an equal force, every part of a stagnating fluid is at rest, and will so continue until disturbed by some external force.

QUESTIONS FOR EXAMINATION.

How is the lateral or side pressure of fluids estimated? —Is the pressure of fluids equal in all directions? — Explain the experiment exhibited by fig. 7. — What is necessary in order that the pressure of fluids should be equal in all directions? — Look to fig. 8, and with that let the subject be further illustrated. — How much heavier is quicksilver than water? — How can lead or any other metal be made to swim in water? — How much heavier than water is lead? — How is it proved that the lead made to swim does not stick to the tube, instead of being acted upon by the upward pressure of the water?

CONVERSATION V.

OF THE HYDROSTATIC PARADOX.

Emma. You are, my dear father, to explain a paradox to-day. I thought natural philosophy had excluded all paradoxes.

Fa. Dr. Johnson has given the definition of a paradox as "an assertion contrary to appearances;" the term is derived from a Greek word compounded of *para* (παρα) "contrary to," and *doxa* (δοξα) "an opinion or expectation." Now, the assertion to which I am to refer you is, "*that any quantity of water, however small, may be made to balance and support any other quantity, however large.*" That a pound of water, for instance, may, without any mechanical assistance, be made to support ten pounds, or a hundred, or even a ton weight, seems at first incredible: certainly it is contrary to what one would expect; and on that account the experiment, to prove this fact, has usually been called the *Hydrostatic paradox:* and a little close examination will satisfy us of its truth.

Ch. It does appear unaccountable. I hope the experiments may be very easy to understand.

Fa. Many have been introduced for the purpose; but I

know of none better than those described by Mr. Ferguson, in his Lectures on select subjects.

O B G H is a glass vessel, consisting of two tubes of very different sizes, joined together, and freely communicating with each other. Let water be poured in at H, which will pass through the joining of the tubes, and rise in the wide one to the same height exactly as it stands in the smaller; which shows that the small column of water in D G balances the large one in the other tube. This will be the case if the quantity ot water in the small tube be a thousand or a million of times less than the quantity in the larger one.

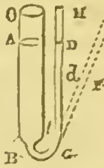
Fig. 10.

If the smaller tube be bent into any oblique position, as G F, the water will stand at F; that is, on the same level as it stands at A. This would be the case if, instead of two tubes, there were any number of them connected together at B, and varied in all kinds of oblique directions; the water would then be on a level in them all; that is, the *perpendicular height* of the water would be the same.

Ch. This elucidation does not seem quite satisfactory; because it appears that a great part of the water in the large tube is supported by the parts B about the bottom, and that therefore the water in the smaller tube only sustains the pressure of a column of water, of a diameter equal to its own.

Fa. This would be the case if the pressure of fluids were downwards only; but we have shown that it acts in all directions; and therefore the pressure of the parts near the side of the tube acts against the column in the middle, which, you suppose, is the only part of the water sustained by that contained in the small tube; consequently, the smaller quantity of water in D B sustains the larger one in A B.

Let us try another experiment.

A B and A B are two vessels, having their bottoms D *d* and D *d* exactly equal; but the contents of one vessel is 20 times greater than that of the other; that is, fig. 11, when filled up to A, will hold but one pint of water, whereas fig. 12, when filled to the same height, will hold 20 pints. Brass bottoms, C C, are fitted exactly to each vessel, and made water tight by pieces of wet leather. Each bottom is joined

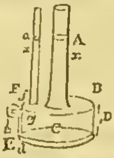
Fig. 11.

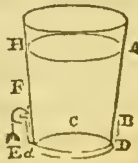
Fig. 12.

to its vessel by a hinge D, so that it opens downwards, like the lid of a box. By means of a little hook, *d*, a pulley, F, and a weight, E, the bottom is kept close to the vessel, and will hold a certain quantity of water.

Em. That is, till the *weight* of the water overcomes the weight E.

Fa. I should rather say, till the *pressure* of the water overcomes the weight E.

Now hold the vessel (fig. 12) upright in your hands, while I gradually pour water into it through a funnel: the pressure bears down the bottom, and, of course, raises the weight, and a small quantity of the water escapes. Mark likewise the height H A, at which the surface of the water stood in the vessel when the bottom began to give way.

Try the other vessel (fig. 11) in the same manner, and we shall see that when the water rises to A, that is, to just the same height in this vessel as in the former, the bottom will also give way, as it did in the other case. Thus equal weights are overcome in the one case by 20 pints of water, and in the other by a single pint. The same would hold good if the difference were greater or less in any given proportion.

Em. What is the reason of this, Papa?

Fa. It depends upon two principles, with which you are acquainted. The first is, that fluids press equally in all directions: and the second is, that action and re-action are equal and contrary to each other.* The water, therefore, below the fixed part B *g f* will press as much upwards against the inner surface, by the action of the small column A *g*, as it would by a column of the *same height*, and of any other diameter: and since action and re-action are equal and contrary, the action against the inner surface B *g f* will cause an equal re-action of the water in the cavity B *f* C C against the bottom C C; consequently the pressure upon C, fig. 11, will be as great as it was upon the same part of fig. 12.

Ch. Can you prove by experiment that there is this upward pressure against the inner surface B *g f*?

Fa. Very easily: Suppose at *f* there were a little cork, with a small string attached to it; I might place a tube over the cork and then draw it out: the consequence of which would be, that the water in the vessel would force itself into the

* See Mechanics, Conversation XI. p. 44.

tube, and stand as high in it as it does in the vessel. Would not this experiment prove that there was this upward pressure against B *gf*?

Ch. It would: and I can easily comprehend that, if other tubes were placed in the same manner, in different parts of B*gf*, the same effect would be produced.

Fa. Then you must admit that the action against B *gf*, or, which is the same thing, the re-action against C C (that is, the pressure of the water against the bottom) is equally as great as it would be if the vessel were as large in every part as it is at the bottom, and the water stood level to the height A A.

Ch. Yes, I do: because if tubes were placed in every part of B*f*, the same effect would be produced in them all, as in the single one at *f*; but if the whole surface were covered with small tubes, there would then be little or no difference between the two vessels, (figs. 11 and 12.)

Fa. There would be no difference, provided you kept filling the large tube, so that the water should stand in them all at the same level, A A: otherwise, the introduction of a single tube, *af*, would make a material difference: for, although the water in A C would overcome the weight E, yet, if with my hand I prevent any of the water from running out till I have taken out the cork, and suffered the water to force itself out of the vessel into the small tube, I may remove my hand with safety; for the water will not overcome the weight now, although there is certainly the same quantity in it as there was before the little tube *af* was inserted.

Em. I think I see the reason of this. The water stood as high as A *a* before the little tube was introduced; but now it stands at the level *xx;* and you told us yesterday that the pressures were equal only when the *perpendicular heights were also equal.*

Fa. I am glad to find you so attentive to my instructions. In order that the pressure may overcome the weight E, you must put in more water till it rises to the level A A; and now you see the weight ascends, and the water flows out.

I will put another tube at *g*, and the water rushing into that causes the level to descend again to *xx;* and more water must be put in to bring the level up to A *a*, before it can overcome the weight E. What I have shown in these two cases will hold true in all, provided you fill the cover with tubes.

Ch. I see, then, that it is the difference of the perpendicular heights which causes the difference of pressure, and I can now fully comprehend the reason why a pint of water may be made to balance or support a hogshead: or, in short, that any "*quantity of a homogeneous fluid, however small, may be made to balance and support any other quantity however large.*"

Em. What is meant by the word *homogeneous?*

Fa. Homogeneous fluids are fluids the particles of which are of the *same kind.* What has been proved with regard to water may be shown to hold with regard to wine, or oil, or any other fluid. But the experiment will not answer if different fluids are made use of, as water and oil together. The term *homogeneous* is derived from two Greek words *homos* (ὁμος) "of the same," and *genos* (γενος) "kind." The principle of the hydrostatic paradox is well illustrated by the *Hydrostatic bellows,* which shall form the subject of our next conversation; but before we close, tell me, Emma, what is your understanding generally of the hydrostatic paradox?

Em. That it depends on the equal pressure of parts of fluids everywhere at the same depth; and what seems to be a paradox is, that any quantity of fluid, however small, may be made to counterpoise and sustain any weight, however large.

QUESTIONS FOR EXAMINATION.

What do you mean by the hydrostatic paradox? — Can you explain Mr. Ferguson's experiment on this subject? See fig. 11 and 12. — How is the upward pressure proved?

CONVERSATION VI.

OF THE HYDROSTATIC BELLOWS.

Father. I think it has been made sufficiently clear that the pressure of fluids *of the same kind* is always proportional to the area of the base, multiplied into the perpendicular height at which the fluid stands, without any regard to the form of the vessel, or the quantity of fluid contained in it.

Em. It still appears, however, very mysterious to me, that the pint of water, as in fig. 11, should have an equal pressure with the 20 pints in the other vessel. You do not mean to say that the one pint weighs as much as the twenty?

Fa. Your objection is proper. The pressure of the water upon the bottom c c does not in the least alter the weight of the vessel and water, considered as one mass; for the action and re-action, which cause the *pressure*, destroy one another with respect to the *weight* of the vessel, which is as much sustained by the action upwards as it is pressed downwards by the re-action.

The *pressure* of water and other fluids differs from the gravity or *weight* in this respect: the *weight* is according to the *quantity;* but the pressure is according to the *perpendicular height.*

Ch. Suppose both vessels were filled with any solid substance, would the effect produced be very different?

Fa. If the water were changed into ice, for instance, the pressure upon the bottom of the smaller vessel would be much less than that upon the larger.

Here is another instrument well adapted to show to you that a very few ounces of water will lift up and sustain a large weight.

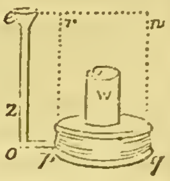

Fig. 13.

Em. What is the instrument called?

Fa. It is made like common bellows, of two flat boards united together by leather or flexible cloth, made water-tight, but without valves; and writers have given it the name of the *Hydrostatic bellows.* This small tin pipe, *e o*, communicates with the inside of the bellows. At present, the upper and lower board are kept close to one another by the weight w. The insides of the boards are not very smooth, so that water may insinuate itself between them: pour this half pint of water into the tube.

Ch. It has separated the boards, and lifted up the weight.

Fa. Thus you see that seven or eight ounces of water have raised, and continue to sustain, a weight of 56 lb. By diminishing the bore of the pipe, and increasing its length, the same or even a smaller quantity of water would raise a much larger weight.

Ch. How do you find the weight that can be raised by this small quantity of water?

Fa. Fill the bellows with water; the boards of which, when distended, are three inches asunder: then screw in the pipe.

As there is no pressure upon the bellows, the water stands in the pipe at *z* at the same level with that in the bellows.

Now place weights on the upper board till the water ascends exactly to the top of the pipe *e*: these weights express the weight of a pillar or column of water, the base of which is equal to the area of the lower board of the bellows, and the height equal to the distance of that board from the top of the pipe.

Em. Will you make the experiment, Papa?

Fa. Yes, if your brother will first make the calculation.

Ch. That I shall be happy to do if I may look to you for a little assistance.

Fa. You will require very little of my help. Measure the diameter of the bellows, and the perpendicular height of the pipe from the bottom board.

Ch. The bellows, which are circular, are 12 inches in diameter; and the height of the pipe is 36 inches.

Fa. Well; you have to find the solid contents of a cylinder of these dimensions; that is, the area of the base multiplied by the height.

Ch. To find the area I multiply the square of 12 inches, that is 144 by the decimals ·7854, and the product is 113, the number of square inches in the area of the bottom board of the bellows. And 113 multiplied by 36 inches, the length of the pipe, gives 4068, the number of cubic inches in such a cylinder: this divided by 1728 (which is the number of cubic inches in a cubic foot) leaves a quotient of 2·3 cubic feet, the solid contents of the cylinder. Still I have not the weight of the water.

Fa. The weight of pure water is equal in all parts of the known world; and a cubic foot of it weighs 1000 ounces.

Ch. Then such a cylinder of water as we have been conversing about weighs 2300 ounces, or 144 pounds, nearly.

Em. Let us now see if the experiment answers to Charles's calculation.

Fa. Well, we will. Put the weights on carefully, or you will dash the water out at the top of the pipe; and I dare say that you will find the fact agrees with the theory.

Ch. If, instead of this pipe, another of double the length were used, would the water sustain a double weight?

Fa It would: and a pipe three or four times the length

would sustain a weight three or four times greater. I will simply observe therefore how you may readily ascertain what weight can be thus supported—thus, every individual portion of the surface of the upper board, equal in area to the section of the tube, is pressed upwards by a force equal to the weight of water in the tube above the level of the upper board: so that if the area of the section of the tube is one square inch, and the surface of the upper board is 100 square inches, then a column of water weighing one pound, will support a weight on the board of 100 pounds.

Ch. Is there, then, no limit to this kind of experiment, except that which may arise from the difficulty of acquiring length in the pipe?

Fa. The bursting of the bellows would soon determine the limit of the experiment. Dr. Goldsmith says that he once saw a strong hogshead of liquor split by this experiment. A small tube of great strength, made of tin, about 20 feet long, was cemented into the bung-hole, and then water was poured through it to fill the cask: when it was full, and the water had risen to within about a foot from the top of the tube, the vessel burst with prodigious force.

Em. It is very difficult to conceive how this pressure acts with such power.

Fa. The water at *o* is pressed with a force proportional to the perpendicular altitude *e o:* this pressure is communicated horizontally in the direction *o p q*, and the pressure so communicated acts, as you know, equally in all directions; the pressure therefore downwards upon the bottom of the bellows is just the same as it would be if *p q n r* were a cylinder of water.

The experiment made on the bellows might, from the want of such an instrument, be made by means of a bladder, in a box with a moveable lid.

Em. Has this property of hydrostatics been applied to any practical purposes?

Fa. The knowledge of it is of vast importance in the concerns of life. On this principle a press of immense power has been formed, which we shall describe when you become acquainted with the nature and structure of valves. This press is used in almost all sea-port towns, for packing into small compass hay and other

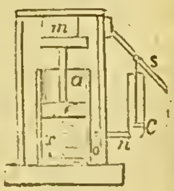

Fig 14

commodities for exportation; and which, in their ordinary state, would take up too much space. It is also now in general use in pressing paper; its great power having entirely superseded hot-pressing; as well as in other manufactures.

In addition to this, the principle is of extensive operation in engineering, and many of the phenomena of nature are explained by it. If a very small portion of water were to lodge to a considerable height in gravel, or other loose earth, behind a wall or embankment, it would exert a lateral pressure sufficient to force the materials from their foundation: hence a sudden shower often causes considerable damage. So likewise if the rain should fill a long narrow chink in a wall, or even in a mountain, though it may fluctuate in its size, and deviate from direct perpendicular height, it may cause extensive devastation, and the mountain be rent with a force equal to the pressure of many thousand tons, though perhaps but one or two tons had been actually employed.

QUESTIONS FOR EXAMINATION.

How is the pressure of fluids of the same kind estimated? — Explain the difference between weight and pressure. — Can you explain the construction and operation of the hydrostatic bellows? — Is there any means of making this small quantity of water bear a still greater weight? — What will set limits to this experiment? — In what manner has a hogshead been burst, and how is the fact to be accounted for?

CONVERSATION VII.

OF THE PRESSURE OF FLUIDS AGAINST THE SIDES OF VESSELS.

Father. Do you recollect, Charles, the law by which you calculate the accelerated velocity of falling bodies?*

Ch. Yes: the velocity increases in the same proportion as the odd numbers 1, 3, 5, 7, 9, &c.; that is, if, at the end of one second of time, a body be carried through 16 feet, then, in the next second, the body will descend three times 16 feet; in the third, it will descend five times 16 feet; and in the next, seven times 16 feet; and so on continually increasing in the same proportion.

* See Mechanics. Conversations VII and VIII.

Fa. How many feet altogether has a body fallen at the end of the *third* second?

Em. I recollect, Papa, that the whole space through which it will fall in three seconds is nine times 16, or 144 feet; because the rule is, that the whole spaces described by falling bodies are in proportion to the squares of the times; and the square of three is nine; therefore, if it fall through 16 feet in the first second, it will in three seconds fall through nine times 16, and in five or eight seconds it will descend in the former case through 25 times 16 feet, and in the latter through 64 times 16 feet; for 25 is the square of five, and 64 is the square of eight. The example of the arrow, which you gave me to calculate, has fixed the rule in my memory.

Fa. Well, then, what I am going to tell you will tend to impress the rule still stronger in your recollection.

The pressure of fluids against the sides of any vessel increases in the same proportion, and is governed by the same laws.

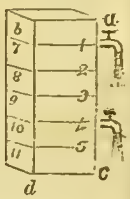

Fig. 15.

Suppose *abcd* to be a rectangular vessel filled with water, or any other fluid, and one of the sides to be accurately divided into any number of equal parts by the lines 1, 7; 2, 8; 3, 9, &c. If the pressure of the water upon the part of the vessel *a* 1 *b* 7 be equal to an ounce or a pound, then the pressure upon the part 1 2 7 8 will be equal to three ounces or three pounds; and the pressure upon the part 2 3 8 9 will be equal to five ounces or five pounds; and so on.

Ch. Now I perceive the reason why the other part of the rule holds true: viz., that the pressure against the whole side must vary as the square of the depth of the vessel.

Fa. Explain then how it operates.

Ch. The pressure upon the *first* part being 1, and that upon the *second* 3, and that upon the *third* 5; then the pressure upon the first and second, taken together, is by addition 4: upon the first, second, and third, it must be 9; and upon the first, second, third, and fourth, it will be 16; but 4, 9, 16, are the squares of 2, 3, 4.

Em. And the pressure upon the whole side *abcd* must be 36 times greater than that upon the small part *a* 1 *b* 7.

Ch. And if there are three vessels, for instance, whose depths are as 1, 2, and 3, the pressure against the side of the

second will be four times greater than that against the first; and the pressure against the side of the third will be nine times greater than that against the first.

Fa. The beautiful simplicity of this rule, and its being the same by which the accelerating velocity of falling bodies is governed, will make it impossible that you should ever forget it.

The use that we shall have to make of this rule by and bye induces me to put this question:—

In two canals, one 5 feet deep, and the other 15; what difference of pressure will there be against the sides of these canals?

Em. The pressure against the one will be as the square of 5, or 25; that against the other will be as the square of 15, or 225; for the latter number divided by the former gives 9 as a quotient, which shows that the pressure against the sides of the deep canal is nine times greater than that against the sides of the shallower one. Cannot this principle be proved by an experiment?

Fa. Yes; by a very simple one: fig. 16 is a vessel of the same size as the last; the bottom and side *b* are of wood, mortised together; the front and opposite sides are glass, carefully inserted in the wooden parts, and made water tight. A thin board, *c*, hanging by two hinges, *xy*, is held close to the glass panes by the pulley and weight, *w*. The board is covered with cloth, and made water-tight.

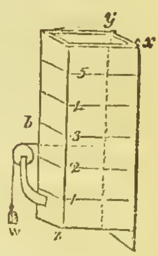

Fig. 16.

Now observe the exact weight which is overcome when the water is poured in and rises to the line 1; then hang on four times that weight, and you will see that water may be poured into the vessel till it rises to the line 2, when the side *c* will give way, and let part of it out.

Em. But why does only a part run away?

Fa. Because, when a small quantity of the water has escaped, the weight, *w*, is greater than the pressure of the water against *c;* therefore the door *c* will be drawn close to the glass panes and confine the rest within the vessel.

You may now hang on a weight nine times greater than the first, and then the vessel will contain water till it rises up to the mark 3, when the side will give way by the pressure, and part of the water escape.

Ch. You have explained the manner of estimating the pressure of fluids against the sides of a vessel. By what rule are we to find the pressure upon the bottom?

Fa. In such vessels as those which we have just described (that is, where the sides are perpendicular to the bottom, and the bottom parallel to the horizon) *the pressure will be equal to the weight of the fluid.*

Em. If, therefore, the vessel *yz* hold a gallon of water, which weighs about eight pounds, the bottom being made moveable, like the side, would a weight of eight pounds keep the water in the vessel?

Fa. It would: for then there would be an equilibrium between the pressure of the water and the weight. And the pressure upon any one side is equal to half the pressure upon the bottom; that is, provided the bottom and sides are equal to one another.

Ch. Pray, Papa, explain how this is.

Fa. The pressure upon the bottom is, as we have shown, equal to the weight of the fluid. But we have also shown that the pressure on the side grows less and less continually, till at the surface it is nothing. Since, then, the pressure upon the bottom is truly represented by the area of the base multiplied into the altitude of the vessel, the pressure upon the side will be represented by the base multiplied into half the altitude.

Em. Is the pressure upon the four sides equal to twice the pressure upon the bottom?

Fa. It is: consequently the pressure of any fluid upon the bottom and four sides of a cubical vessel is equal to three times the weight of the fluid.

Can you, Charles, tell me the difference between the *weight* and the *pressure* of a conical vessel of water standing on its base?

Ch. The *weight* of a conical vessel of any fluid is found by multiplying the area of the base by *one third part* of its perpendicular height: but the *pressure* is found by multiplying the base by the whole perpendicular height; therefore the pressure upon the base will be equal to three times the weight. I think when I was learning mensuration, that the rule for finding the solidity of a cone, or a pyramid, is this: "multiply the area of the base by $\frac{1}{3}$ of the height, and the product will be the solidity."

Em. How do you ascertain the pressure, Papa, upon other surfaces besides those which are horizontal?

Fa. Whether the sides or surfaces be perpendicular, horizontal, or oblique, the pressure of a body of water is always equal to the product of the surface multiplied by the depth of its centre of gravity.

Ch. Will you be kind enough to explain this, Papa?

Fa. Suppose you wish to find the pressure upon the sloping side of a pond: you must drop a plumb-line from the water to the middle of the sloping side, just half-way between the surface of the water and the bottom, and multiply the length of the plumb-line under water, by the area of the surface covered with water; so that if the line is 10 feet, there will be upon every 6 feet square of that side a pressure of about 10 tons: you may set it down as a general rule, that the pressure of fresh water is always about 13 pounds upon every square inch of level bottom at the depth of 30 feet, whatever may be the form or position of the sides; and so in proportion for greater or less depths: if the sides are perpendicular, and of whatever shape, provided the width of the pond or vessel is the same all the way down, the pressure on every square inch of the sides is nearly 13 pounds at the depth of 30 feet, and so in proportion for greater or less depths.

QUESTIONS FOR EXAMINATION.

What is the law of the pressure of fluids against the sides of any vessel?— Explain the subject by means of fig. 15. — Can you tell me why the pressure against the whole side of a vessel must vary as the square of the depth of the vessel? — Suppose you have three vessels whose depths are as 1, 2, and 3; what will be the proportional pressures against the several sides? — What will be the difference of pressure against the sides of two canals, the depth of one being five feet, and that of the other fifteen? — How is this proved by experiment? — How is the pressure against the bottom of a vessel estimated? — What is the pressure upon any side of a cubical vessel, and what is the reason of it? — What is the pressure upon the four sides equal to? — What is the difference between the weight and the pressure of a conical vessel of water standing on its base?

CONVERSATION VIII.

OF THE MOTION OF FLUIDS.

Father. We will now consider the pressure of fluids with regard to the motion of them through spouting-pipes, which

is subjeet to the same law. This forms a portion of Hydraulies.

If the pipes at 1 and 4 (fig. 15) be equal in size and length, the diseharge of water by the pipe at 4 will be double that at 1. Beeause the velocity with which water spouts out at a hole in the side or bottom of a vessel is as the *square-root* of the distanee of the hole below the surfaee of the water: or in other words, the velocity and quantity are in proportion to the square-root of the depth.

Em. What do you mean by the square-root?

Fa. The square-root of any number is that which, being multiplied into itself, produees the said number. Thus the square-root of 1 is 1; but of 4 it is 2; of 9 it is 3; and of 16 it is 4, and so on.

Ch. Then if you had a tall vessel of water, with a tap inserted within a foot of the top, and you wished to draw the liquid off three times faster than it eould be done with that, what would you do?

Fa. I should take another tap of the same size, and insert it into the barrel at nine feet distance from the surface, and the thing required would be done.

Em. Is this the reason why the water runs so slowly out of the eistern when it is nearly empty, in comparison with its force when the cistern is full?

Fa. It is: because the more water there is in tne cistern, the greater the pressure upon the part where the tap is inserted; and in proportion to that pressure, the velocity and quantity of water running out is increased.

In some large barrels there are two holes for cocks or taps, one about the middle of the cask, the other at the bottom; now if when the vessel is full you draw the beer or wine from both eocks at once, you will find that the lower one gives out the liquor eonsiderably faster.

Ch. How do you estimate the proportion, Papa?

Fa. Just as the square-root of 2 is to that of 1. While a quart was running from the upper cock, three pints, nearly, would run from the lower one.

Em. Are we, then, to understand, that the *prcssure* against the side of a vessel increases in proportion to the *square* of the depth; when the *velocity of a spouting pipe*, which depends upon the pressure, increases only as the *square-root* of the depth?

Fa. That is the proper distinction.

Ch. Is not the velocity of water running out of a vessel that empties itself continually decreasing?

Fa. Certainly: because, in proportion to the quantity drawn off, the surface descends, and consequently, the perpendicular depths become less and less.

The spaces described by the descending surface, in equal portions of time, are as the odd numbers 1, 3, 5, 7, 9, &c., taken backwards.

Em. If the height of a vessel filled with any fluid be divided into 25 parts, and in a given space of time, as a minute, the surface descend through nine of those parts, will it in the next minute descend through seven of those parts, and the third minute five, in the fourth three, and in the fifth one?

Fa. This is the law; and from it have been invented *clepsydras,* or water clocks.

Ch. Why are they so called; and how are they constructed, Papa?

Fa. The term *clepsydra* is derived from the Greek word *clepsudra* (κλεψύδρα,) a word compounded of *clepto* (κλεπτω) "to conceal," and *hudor* (ὕδωρ) "water." Water clocks were first brought into Egypt under the reign of the Ptolemies, and commonly used in Rome during the winter season, sun-dials superseding them in the summer. Before the invention of clocks and watches, they were very general for the admeasurement of small portions of time: and the revival of their use has been proposed by the late Captain Kater, but adopting mercury instead of water. To construct a clepsydra, take a cylindrical vessel, and, having ascertained the time it will require to empty itself, divide the surface, by lines, into portions which are to one another as the odd numbers 1, 3, 5, 7, &c.

Em. Suppose the vessel requires six hours to empty itself; how must it be divided?

Fa. It must be first divided into 36 equal parts; then, beginning from the surface, take eleven of those parts for the first hour, nine for the second, seven for the third, five for the fourth, three for the fifth, and one for the sixth: and you will find that the surface of the water will descend regularly through each of these divisions in an hour.

But reverting to the great force of water; I believe both of

you have seen the locks that are constructed on various rivers and canals.

Ch. Yes: and I have wondered why the flood-gates were made of such an enormous thickness.

Fa. But, after what you have heard respecting the pressure of fluids, you will see the necessity there is for the great strength employed.

Ch. I do: for sometimes the height of the water is 20 or 30 times greater on one side of the gates than it is on the other; therefore the pressure will be 400 or even 900 times greater against one side than it is against the other.

Em. How are the gates opened when such a weight presses against them?

Fa. No power could be well employed to move them when this weight of water is against them: therefore there are side sluices, which being drawn up, the water escapes through them, till it becomes level on both sides: then the gates are opened with the greatest ease; because, the pressure being equal on both sides, a small force applied will be sufficient to overcome the friction of the hinges or other comparatively trifling obstacles.

Ch. Is it this great pressure that sometimes beats down the banks of rivers?

Fa. Certainly: for if the banks of a river or canal do not increase in strength in the proportion of the square of the depth, they cannot stand. Sometimes the water in a river will insinuate itself through the bank near the bottom; and if the weight of the bank be not equal to that of the water, it will assuredly be torn up, and perhaps with great violence.

I will make the matter clear by a figure. Suppose this figure be a section of a river, and *c* a crevice or drain made by time under the bank *g*. By what we have shown before, the upward pressure of the water in that drain is equal to the downward pressure of the water in the river: therefore, if that part of the bank be not as heavy as a column of water of the same height and width, it must be torn up by the force of the pressure.

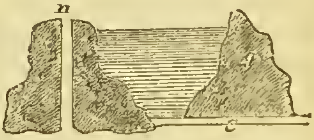

Fig. 17.

QUESTIONS FOR EXAMINATION

Explain by fig. 15, the motion of fluids through pipes. — By what law is the velocity of spouting fluids governed? —How is this practically applicable?— Why does water run slowly out of a cistern when almost empty? — In a barrel of porter standing on its head, having two cocks, one in the middle and the other near the bottom, which will give out the liquor the fastest, and in what proportion? — Point out the distinction which arises between the pressure against the side of a vessel, and the velocity of a spouting pipe. — Does the velocity of a running fluid continually decrease, and why? — How are water-clocks constructed?—How would you divide a vessel of this kind that would require six hours to empty itself? — Why are the flood-gates to locks made so thick?—How are they opened when such a weight presses upon them? — What effect has the pressure of water on the banks of a river? — Can you explain this by the aid of fig. 17?

CONVERSATION IX.

OF THE MOTION OF FLUIDS—*continued.*

Father. I will now show you an experiment by which you will observe the uniformity of nature's operations in regard to spouting fluids.

Ch. Do you refer to any other facts besides those which relate to the quantity of water issuing from pipes?

Fa. Yes. Let A B represent a tall vessel of water, which must be always kept full while the experiments are making. From the centre of this vessel I have drawn a semicircle, the diameter of which is the height of the vessel A B. I have drawn three lines; *d* 2, from the centre of the vessel, *c* 1, *a* 5, at equal distances from the centre; the one above and the other below it: all three are drawn perpendicular to the vessel. By taking out the plug from the centre, you will see the water spout to M. Take your compasses, and you will find that the distance N M is exactly double the length of *d* 2. I will now stop this plug, and open the next below.

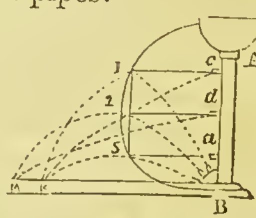

Fig. 18.

Ch. The water reaches to K, which is double the length of *a* 5.

Fa. Try in the same manner the pipe *c.*

Ch. It falls at the same spot, K, as it did from the lower one.

Fa. Because, the lines *c* 1 and *a* 5 being equally distant from the centre, *d*, of the circle, are equal to each other.

Em. Then N K is the double of *c* 1, as well as of *a* 5.

Fa. It is. The general rule deduced from these experiments is, that the horizontal distance to which a fluid will spout from an horizontal pipe, in any part of the side of an upright vessel below the surface of the fluid, is equal to twice the length of a perpendicular to the side of the vessel drawn from the mouth of the pipe to a semicircle described upon the altitude of the vessel.

Can you, Charles, tell me in what part the pipe should be placed, in order that the fluid should spout the farthest possible?

Ch. In the centre: for the line *d* 2 seems to be the greatest of all the lines that can be drawn from the vessel to the curved line.

Fa. Yes; it is demonstrable by geometry that this is the case; and that lines at equal distances from the centre, above and below, are also equal to each other.

Em. Then in all cases, if pipes are placed equally distant from the centre, they will spout to the same point.

Fa. They will. Instead of horizontal pipes, I will fix three others near N, which shall point obliquely upwards at different angles; one at 22° 30′, the second at 45°, and the third at 67° 30′; and you will see that, when I open the cocks, the water will cut the curve line in those places to which the horizontal lines were drawn.

Ch. That which spouts from the centre is thrown to the point M, as it was from the centre horizontal pipe. The two others fall on the point K, on which the upper and lower horizontal pipes ejected the stream.

Em. I thought the water from the upper cock did not reach so high as the mark.

Fa. It did not. The reason is, that it had to pass through a larger body of air; and the resistance from that retarded the water, and prevented it from ascending to the point to which it would have ascended if the air had been away.

While we are on this subject, I will just mention, that as you see the water spouts the furthest when the pipe is elevated to an angle of 45°, so a gun, cannon, &c. will project a bullet the furthest if it be also elevated to the same angle.

Ch. Will a cannon or mortar carry a ball the same distance if it be elevated at angles equally distant from 45°, the one above, and the other below?

Fa. It will, in theory: but, owing to the great resistance which very swift motions have to encounter from the air, there must be allowances made for a considerable variation between theory and practice.

A regard to this will explain the reason why water will not rise so high in a jet as it does in a tube.

Em. I do not know what this means.

Fa. You have seen a fountain?

Em. Yes; I have often been amused with that near the Temple-gardens.

Fa. Fountains are usually called *jets*, from the French term, *jets d'eau*, from *jeter*, "to cast or throw up." Now if the water of that in the Temple ascended through a pipe, it would rise higher than in the open air. Turn to fig. 10; the water in the small tube rises to a level with that in the larger one; but if the tube H G were broken off at *t*, the water would spout up like a fountain, but not so high as it stands in the tube, perhaps no higher than to *d*.

Ch. Is that owing entirely to the resistance of the air?

Fa. It is to be ascribed to the resistance which the water meets with from the air, from the friction also against the sides of the spout, and to the force of gravity, which has a tendency to retard the motion of the stream.

Em. Why does the fountain in the Temple sometimes rise higher and sometimes lower?

Fa. Near the Temple-gardens there is a reservoir of water, from which a pipe communicates with the jet in the fountain; and according to the quantity of water in the reservoir, the ascent is higher or lower.

Ch. By turning a cock near the pump the height is instantly lowered.

Fa. That cock is likewise connected with the reservoir; and therefore, taking water from it must have the effect of lowering the stream at the fountain, as well as the water in the reservoir.

Em. It, however, soon recovers its force.

Fa. Yes; because there is a constant supply of water to the reservoir, which, not coming in so quickly as the cock

lets it out, the fountain cannot always play to the same height. The velocity with which water issues from an orifice is equal to that which would be acquired by a heavy body in falling through a height equal to the difference between the levels of the orifice and the fountain head, the principal causes which prevent the jet from reaching the height which theory assigns to it are—1st, the resistance of the air proportional nearly to the square of the velocity; 2nd, the friction against the sides of the pipe, and the orifice through which the water issues; 3rd, the decreasing velocity of the particles in the ascent, and the pressure of the lower particles on those immediately above, and the consequent shortening and enlarging of the column of water; 4th, the water, after all its velocity is spent, resting on the particles below it, and by their pressure retarding the velocity of the whole column: to avoid which, however, slightly inclining the jet from the perpendicular has been found by experience to be the best remedy: the jet also by this means plays considerably higher, though the effect is not so pleasing. It must be borne in mind that the diameter of the orifice, or, as it is sometimes called, from the French, the *adjutage*, of the jet should be much less than that of the pipe.

From what you have already learnt on this subject, you will be able to know how London and other places are supplied with water.

Ch. London is partly supplied from the New-river; partly from the Thames at Chelsea, and other places.

Fa. The New-river is a stream of water that comes from Ware in Hertfordshire: it runs into a reservoir situated on the high ground near Islington. From this reservoir pipes are laid into those parts of the city that have their water from the New-river; and through these pipes the water flows into the cisterns belonging to the different houses.

Em. The reservoir of Islington must, of course, be higher than the cisterns in London.

Fa. Certainly; because water will not rise above its level. On this account some of the higher parts of town have been supplied from Hampstead; and others are supplied from the Thames, by means of the water-works at Chelsea and elsewhere.

Ch Are pipes laid all the way from Chelsea to town?

Fa. Yes: but these supply the intermediate places, as well as London; and Hampstead standing so high, the water is carried up into the first and second stories in certain houses. Thus you see that water may be carried to any distance, and houses on different sides of a deep valley may be supplied by water from the same spring head. You must remember that, if the valleys are very deep, the pipes must be exceedingly strong near the bottom, because the pressure increases in the rapid proportion of the odd numbers 1, 3, 5, 7, &c.; and, therefore, unless the strength of the wood or iron be increased in the same proportion, the pipes will be continually bursting.

Em. You told me, the other day, that the large mound of earth (for it appears to be nothing else) near the end of Tottenham-court-road, was intended as a reservoir for the New-river.

Fa. I did: that unsightly mound contains an exceedingly large basin, capable of containing a great many thousand hogsheads of water.

Ch. How can they get the water into it?

Fa. At Islington, near the New-river Head, is made a large reservoir upon some very high ground; into which, by means of a steam-engine, they can constantly throw water from the New-river. This reservoir being higher than that in Tottenham-court-road, supplies the latter with water through pipes, and keeps it constantly full.

By this contrivance the New-river company have been able to extend their business to other parts of London.

Ch. The weight of water in this place must be immensely great.

Fa. Yes: and therefore the necessity of the great thickness of earth which you observe against the wall, towards the bottom of the mound. The thickness lessens towards the top, as there the pressure of water is not so great.

Em. Would not the consequences be very serious if the water were to break through the earth at the bottom?

Fa. If such an accident were to happen when the reservoir was full of water, it would probably tear up the works and do incredible mischief. To prevent this, the vast bank of earth is sloped within, as well as without, and covered with a strong coating of clay; and thick brick-work carefully tarrassed over, keeps the whole mass as firm and compact as the neces-

sity of the case requires. Natural reservoirs of water are seldom found near the summit of a hill, for there are not rills and small streams suffieient to keep it supplied, and without a reservoir there eannot of eourse be any spring. In sueh cases, therefore, it is usual to construet wells, whieh are then generally very deep, before a spring can be met with, and then the water rises only as high as the reservoir from whenee it flows. Where reservoirs of water are found in elevated situations, the springs that supply them must run from some higher hills in the neighbourhood.

QUESTIONS FOR EXAMINATION.

Can you explain the experiment exhibited by fig. 18?—What general rule is deducible from this experiment?—In what part of the side of a vessel should a pipe be plaeed, in order that the fluid should spout the furthest possible?—Can you place two other pipes which shall spout to equal distanees?—To what angle must a cannon be elevated to projeet a ball the furthest possible?—Why will not water rise so high in a jet as a tube?—Will water in a pipe, or in the open air, as in a fountain, rise the highest?—Is there any other eause besides the resistance of the air that prevents a stream from a fountain rising as high as the head of the water from which it proceeds?—How is London supplied with water from the New-river?—How must the reservoir whieh is called the New-river Head be situated?—Can water be carried to any distance?—For what reason is it necessary that the pipes should be made very strong if they are earried down in deep vallies?

CONVERSATION X.

OF THE SPECIFIC GRAVITIES OF BODIES.

Emma. What is the reason, Papa, that some bodies, sueh as lead or iron, if thrown into the water, sink, while others will swim?

Fa. Beeause some bodies are heavier and some lighter than water.

Em. I do not quite comprehend that. A pound of wood, another of water, and another of lead, are all equally heavy, as I was told the other day, when Charles played me a triek. You recolleet that he suddenly asked me which was the heavier of the two, a pound of lead or a pound of feathers. I said the lead, and you all laughed at me: by which I was eonvinced that a pound, or 16 ounees of any substanee whatever, must be always equal to the same weight of any other.

Fa. You are not the first person deceived by this question.

It is a common trick. Although a pound of lead and another of water be equally heavy, yet they are not of equal magnitudes. Do you know how much water weighs a pound?

Ch. Yes; about a pint.

Fa. Do you think that, if I were to fill the same pint measure with lead, it would then weigh no more than a pound?

Ch. Certainly not, Papa. That would weigh a great deal more. I do not believe that the 14 pound weight we have is much larger than a pint measure.

Fa. Yes, it is, by about a fourth part. The same measure that contains one pound of water, would however contain about 11 pounds of lead; but it would contain 14 pounds of quicksilver, which, you know, I could pour into the vessel as readily as if it were water.

Here are two cups of equal size. Fill one with water, and I will fill the other with quicksilver. Now take the cups in your hand, and tell me which is heaviest.

Ch. The quicksilver is considerably heavier.

Fa. The cups, however, are of equal size.

Em. Then there must be equal quantities of water and quicksilver.

Fa. They are equal in bulk.

Ch. But very unequal in weight. Shall I try how much heavier the one is than the other?

Fa. If you like. In what manner will you ascertain the fact?

Ch. I will carefully weigh the two cups, and then, dividing the larger weight by the smaller, I shall see how many times heavier the quicksilver is than the water.

Fa. You will not succeed accurately by that means; because the weight of the cups is probably equal; but by this method they ought to differ in weight in the same proportion as the two substances.

Em. Then pour the quicksilver first into the scale, and weigh it: afterwards, do the same with the water, and divide the former by the latter. Will not that give the result?

Fa. Yes. You may also make the experiment thus:

Here is a small phial, that weighs, now it is empty, an ounce; when filled with pure rain water, the weight of the whole will be two ounces. Weigh it, and convince yourself.

Ch. I find that it does: the water weighing one ounce.

Fa. Now pour out the water, and let the phial be well dried both within and without. Then fill it very accurately with quicksilver, and weigh it again.

Em. It weighs a little more than 15 ounces: but, as the bottle weighs one ounce, the quicksilver weighs something more than 14 ounces.

Fa. What do you infer from this, Charles?

Ch. That the quicksilver is more than 14 times heavier than water.

Fa. I will now pour away the quicksilver, and fill the phial with pure spirit of wine, or, as the chemists call it, *alcohol*, an Arabic term signifying *the spirit*, by which is implied, spirit as highly rectified as possible.

Em. It does not weigh two ounces: now, consequently, the fluid does not weigh an ounce. The *alcohol*, therefore, is lighter than water.

Fa. By these means, which you cannot fail of understanding, we have obtained the *comparative weights* of three fluids. Philosophers, as I have before told you, call these comparative weights, the *specific gravities* of the fluids: they have agreed also to make pure rain, or distilled water, at a given temperature, the standard to which they refer the comparative weights of all other bodies, whether solid or fluid.

Ch. Is there any particular reason why they prefer water to every other substance?

Fa. I told you, a few days ago, that water, if very pure, is of the same weight in all parts of the world: and, what is very remarkable, a cubic foot of water weighs exactly a thousand ounces avoirdupois. On these accounts it is admirably adapted for a standard; because you can at once tell the weight of a cubic foot of any other substance if you know its specific gravity.

Em. A cubic foot of quicksilver weighs therefore 14,000 ounces.

Fa. Yes; and lead is eleven times heavier than water, so that a cubic foot of it will weigh 11,000 ounces. In England the temperature is usually taken at 62° of Fahrenheit's scale; the French take it at 32°, or that of melting ice; and sometimes at the temperature at which its density is the greatest, viz. about 39·4° of Fahrenheit. This latter is esteemed the most convenient, in being more easily main-

tained without variations; for the temperature of 62° is continually exposed to the fluctuations of the temperature of the air. It is only when great precision is required that much attention is paid to the particular temperature of the water; and then some correcting influence can be applied dependent on the known density of the water at the different degrees of the thermometric scale.

QUESTIONS FOR EXAMINATION.

Why do some bodies swim and others sink? — Do equal weights of different substances occupy equal spaces?—How would you get at the weights accurately of two equal quantities of fluid?— How do you find that quicksilver is 14 times heavier than water? — Compare now the weight of alcohol with that of water. — What are the comparative weights of bodies called?—Is rain-water equally heavy everywhere, and how much does it weigh?

CONVERSATION XI.

OF THE SPECIFIC GRAVITIES OF BODIES.

Father. Before we enter upon the methods of obtaining the specific gravities of different bodies, it will be right to premise a few particulars, which should be well understood.

You understand that the specific gravity of different bodies depends upon the different quantities of matter which equal bulks of these bodies contain.

Ch. As the *momentum** of different bodies is estimated by the quantity of matter when the velocity is the same; so the specific gravity of bodies is estimated by the quantities of matter when the bulks or magnitudes are the same. This, I believe, is what you mean.

Fa. Yes: if you weigh a piece of wood, and a piece of lead, both exactly equal in size to a copper penny-piece, the former will be found lighter, and the latter considerably heavier, than the copper.

Ch. And, therefore, I should say that the specific gravity of the wood is less than that of the copper; and that of the lead greater.

Em. Is it the *density* therefore that constitutes the specific gravity?

Fa. Undoubtedly it is: and, as we observed yesterday,

* See Mechanics, Conversation VI.

water is employed as a medium to discover the different specific gravities of different bodies; and is also a standard to which they may be all referred.

Here are three pieces of different kinds of wood, which I will put into this vessel of water: one sinks to the bottom; a second remains in any position in the water where it is placed; and the third swims on the water, with more than half of the substance above its surface.

Ch. The first, then, is heavier than the water; the second is of the same weight with an equal bulk of the fluid; and the third is lighter.

Fa. Since fluids press in all directions, a solid immersed in water sustains a pressure on all sides, which is increased in proportion to the height of the fluid above the solid.

Em. That seems natural; but an experiment would fix it better in the mind.

Fa. Well then; tie a leathern bag (fig. 8) to the end of a glass tube, and pour in some quicksilver. Dip the bag in water, and the upward pressure of the fluid will raise the quicksilver in the tube; the ascent of which will be higher or lower, in proportion to the height of the water above the bag.

Em. I now understand that the upper part of the tube being empty, or, at least, only filled with air, the upward pressure of the water against the bag must be greater than the downward pressure of the air; and that, as the pressure increases according to the depth, so the mercury must keep rising in the tube.

What is the reason that a body heavier than water, such as a stone, sinks to the bottom, if the pressure upward is always equal to that downward?

Fa. This is a very proper question. The stone endeavours to descend by the force of gravity: but it cannot descend without moving away as much of the water as is equal to the bulk of the stone; therefore it is resisted, or pressed upwards, by a force equal to the weight of as much water as is equal in magnitude to the bulk of the stone: but the weight of the water is less than that of the stone; consequently the force, pressing against it upwards, is *less* than its tendency downwards: and therefore it will sink with the *difference* of these two forces.

You will now, I should think, be at no loss to understand the reason why bodies lighter than water swim.

Ch. The water being heavier, the force upwards is greater than the natural gravity of the body; and it will be buoyed up by the difference of the forces.

Fa. Bodies of this kind, then, will sink in water, till so much of them is below the surface, that a bulk of water equal to the bulk of the part of the body which is below the surface is of a weight equal to the weight of the whole body.

Em. Will you explain this more particularly?

Fa. Suppose the body to be a piece of wood, part of which will be above and part below the surface of the water: in this state conceive the wood to be frozen in the water.

Ch. I suppose that if the wood be taken out of the ice, a vacuity will be left, and the quantity of water that is required to fill that vacuity will weigh as much as the whole substance of the wood.

Fa. Exactly so.

There is one case remaining. Where equal bulks of water and wood are of the same weight, the force with which the wood endeavours to descend, and the force that opposes it, being equal to one another, and acting in contrary directions, the body will rest between them, so as neither to sink by its own weight, nor to ascend by the upper pressure of the water.

Em. What is the meaning of this glass jar with little figures in it?

Fa. I placed it on the table, in order to illustrate our subject to-day. You observe that, by pressing the bladder with my hand, the three figures sink.

Em. But not at the same moment.

Fa. The figures are made of glass, and have the same specific gravity as the water surrounding them, or perhaps, rather less; and, consequently, they all float near the surface. They are hollow, with little holes in the feet. When the air which lies between the bladder and the surface of the water is pressed by my hand, there is a pressure on the water, which is communicated through it; and that part of it which lies contiguous to the feet of the images will be forced into their bodies; by which their weight is so much increased as to render them heavier than the water, and therefore they descend.

Fig. 19.

Ch. Why do they not all descend to the same depth?

Fa. Because the hollow part of the figure E is larger than the hollow part of D; and that is larger than that of C: consequently, the same pressure will force more water into E than into D, and more into D than into C.

Em. Why do they begin to ascend now you have taken your hand away?

Fa. I told you that the hollow parts of the figures were empty, which was not quite correct; they were full of air, which, as it could not escape, was compressed into a smaller space when the water was forced in by the pressure upon the bladder: but, as soon as the pressure is removed, the air in the figures expands, drives out the water, and they become as light as at first, and will therefore rise to the surface.

Ch. The figures, I observed, in rising up to the surface, turned round: how is this, Papa?

Fa. This circular motion is in consequence of the hole being on one side; and when the pressure is taken off, the water, issuing out quickly, is resisted by the water in the vessel, and the reaction, being exerted on one foot, turns the figure round.

Ch. How is the specific gravity of different substances most readily to be ascertained, Papa?

Fa. The specific gravity of a solid substance as compared with that of a liquid is to be ascertained by weighing an equal bulk of each. But this operation being extremely difficult, since it requires the substances to be compared to be formed accurately into the same shape and size; and as many indeed cannot be changed as to their shape without destroying their value, and so cannot be compared at all, as diamonds, precious stones, crystals, certain metallic ores, and many animal and vegetable substances, the *Hydrostatic balance* has been invented upon the principles above explained, which presents the most easy and accurate method of comparing all substances whether solid or fluid; but this shall form the subject of our next conversation, when I hope satisfactorily to explain it to you.

QUESTIONS FOR EXAMINATION.

Upon what do the specific gravities of different bodies depend? — Make the comparison between equal bulks of lead, copper, and wood. — What then constitutes the difference in the specific gravities of bodies? — What is usually

made a medium to compare the specific gravity of bodies? — Make the comparison in water with three pieces of wood. —What kind of pressure does a solid sustain wheu immersed in a fluid? — Make the experiment as it is shown by fig. 8, explain its principle and the result. —Why does a stone sink in water if the pressure upward is equal to the downward pressure? —How far will bodies that are lighter than water sink in that fluid? — Explain this more particularly.—If a piece of wood, the specific gravity of which is just equal to that of water, be placed in a vessel of that fluid, what will be the consequence? —Explain what is meant by fig. 19.

CONVERSATION XII.

OF THE METHODS OF FINDING THE SPECIFIC GRAVITY OF BODIES.

Emma. Pray, Papa, of what use are these scales?

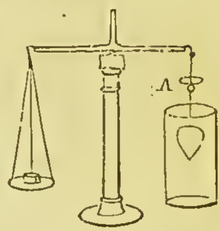

Fig. 20.

Fa. They are called the hydrostatic balance; which differs but little from the balance in common use. Some instruments of this kind are more complicated; but the most simple are best adapted to my purpose. You observe that to the beam two scale-pans are adjusted, which may be taken off at pleasure. There is also another pan, A, of equal weight with one of the others, furnished with shorter strings and a small hook, so that any body may be hung on it, and then immersed in the vessel of water B.

Ch. Is it by means of this instrument that you find the specific gravity of different bodies?

Fa. It is. I will first give you the rule, and then illustrate it by experiment. The rule should be committed to memory.

"Weigh the body first in air; that is, in the common way; then weigh it in water. Observe how much weight it loses by being weighed in water; and, if you divide the former weight by the loss sustained, the result is, its specific gravity compared with that of the water."

I will give you an example. Here is a guinea: it weighs in the air 129 grains: I suspend it by a fine thread of horsehair to the hook at the bottom of the pan A; and you see that, by being immersed in water, it weighs only $121\frac{3}{4}$ grains.

Em. Then, in the water it has lost of its weight $7\frac{1}{4}$ grains.

Fa. Well: now divide 129 by $7\frac{1}{4}$, or rather, turn the $\frac{1}{4}$ into decimals, and divide by 7·25.

Ch. But I must first add two cyphers to the 129 grains; because there must always be as many decimals in the dividend as there are in the divisor. And 129·00 divided by 7·25 gives for the quotient more than 17.

Fa. The gold is therefore more than 17 times heavier than water.

Em. I do not understand the reason of this.

Fa. Do you not? Well, we will attempt another elucidation. In this scale is a basin, filled accurately to the brim with water. I now put a piece of mahogany into it very gently; although anything else would answer the same purpose.

Em. The water runs over into the scale, I perceive.

Fa. Yes, as I expected; now wait a moment, and you will find everything at rest, and the basin quite as full as it was at first, except that the wood and water together fill the basin; whereas it was all water before. I will now take away the basin, and put the mahogany by itself into the other scale.

Em. It balances the water that ran out of the basin.

Ch. The mahogany therefore displaced a quantity of water equal to itself in weight.

Fa. And so did the guinea just now; and if you had taken the same precaution, you would have found that the quantity of water equal in bulk to the guinea weighed $7\frac{1}{4}$ grains, the weight which it lost by being weighed in the fluid.

Em. Am I to understand that what any substance loses of its weight, by being immersed in water, is equal to the weight of a quantity of water of the same bulk as the substance itself?

Fa. Yes; if the body be wholly immersed in water: and with regard to all substances that are specifically heavier than water, you may take it as an axiom, that "every body when immersed in water, loses as much of its weight as is equal to the weight of a bulk of water of the same magnitude."

I will now place this empty box on the basin filled to the edge with water, and, as before, it drives over a quantity of the fluid equal in weight to itself. Put in two penny-pieces, and you will perceive the box sink deeper into the water.

Ch. Yes; and they drive more water over: as much, I suppose, as is equal in weight to the copper coins.

Fa. You are right. Now, can you tell me how long you could go on loading the box?

Ch. Till the weight of the copper and box, taken together, is something greater than the weight of as much water as is equal in bulk to the box.

Fa. You understand, then, the reason why boats, barges, and other vessels, swim on water; and to what extent you may load them with safety.

Em. They will swim so long as the weight of the vessel and its lading together is less than that of a quantity of water equal in bulk to the vessel.

Fa. Certainly: can you, Charles, devise any method to make iron or lead swim, although they are so much heavier than water?

Ch. I think I can. If the metal be beaten out very thin, and the edges turned up, I can easily conceive that a box or a boat formed of it may be made to swim. Of this kind is the copper ball, which is contrived to turn off the water when the cistern is full.

Em. I have often wondered how that operates.

Fa. If, upon reflection, you could not satisfy yourself about the mode of its acting, you should have asked, my dear child. It is better to get information from another than to remain ignorant.

The ball, though made of copper, which is eight or nine times heavier than water, is beaten out so thin, that its bulk is much lighter than an equal bulk of water. By means of a handle it is fastened to the cock, through which the water flows; and, as it sinks or rises, it opens or shuts the cock.

If the cistern is empty, the ball hangs down, and the cock is open, to admit a supply of water freely: as the water rises in the cistern, it reaches the ball, which, being lighter than the water, rises with it, and, by rising, gradually shuts the cock; and, if it be properly placed, it is contrived to shut the cock just at the moment that the cistern is full.

On the same principle, boats of iron are now constructed. They will last longer than wood, and cause less friction in passing through the water.

I will now give you a few examples to exercise your knowledge of this subject. Can you, Emma, find the specific gravity of this piece of silver?

Em. It weighs in air 318 grains. I now fasten it to the hook with the horse-hair, and it weighs in water 288 grains, which, taken from 318, leave 30, the weight it lost in water. By dividing 318 by 30, the quotient is about $10\frac{1}{2}$; consequently the specific gravity of the silver is ten and a half times greater than that of water.

Fa. What is the specific gravity of this piece of glass? It weighs 12 penny-weights in air.

Ch. In water it weighs only 8, losing, consequently, 4 by immersion: and 12 divided by 4 gives 3; therefore the specific gravity of glass is 3 times greater than that of water.

Fa. True; but bear in mind, that this is not the case with all kinds of glass: for the specific gravity of glass varies from 2 to almost 4.

Here is an ounce of quicksilver; tell me its specific gravity by the method we have been considering.

Em. How is that to be managed, Papa? for we cannot hang it upon the balance.

Fa. But you may suspend this glass bucket on the hook at the bottom of A. Immerse it in the water, and then balance it exactly with weights in the opposite scale.

I will now put into the bucket the ounce, or 480 grains, of quicksilver, and see how much it loses in water.

Fig. 21.

Ch. It weighs 445 grains; and consequently it lost 35 grains by immersion: and 480 divided by 35 give almost 14; so that mercury is nearly 14 times heavier than water.

Fa. In the same manner we obtain the specific gravity of all bodies that consist of small fragments. They must be put into the glass bucket and weighed; and then, if from the weight of the bucket and body in the fluid you subtract the weight of the bucket, there remains the weight of the body in the fluid.

Em. Why do you make use of horse-hair to suspend the substances? Would not silk or thread do as well?

Fa. Horse-hair is by far the best; for it is very nearly of the specific gravity of water; and its substance is of such a nature as not to imbibe moisture.

Em. How would you ascertain, Papa, the specific gravity of substances lighter than water?

Fa. Upon the same principles and with the same instrument; but they must be fixed to a stiff pin attached to the bottom of one scale, the scales being counterpoised before the pin is plunged into the water, or by loading the substance with a weight heavier than water, and allowance made for the difference of its weight in air and water; but we will advert to this more at large in our next conversation.

QUESTIONS FOR EXAMINATION.

Explain the structure and uses of the hydrostatical balance. — What is the rule for finding the specific gravity of bodies? — Explain this by instance of a guinea. — Tell me the reason why boats, &c., swim and to what extent they may safely be loaded. — Can iron be made to swim? — How does a copper ball act in turning off water when a cistern is full? — How would you find the specific gravity of a piece of silver? — What is the specific gravity of a piece of glass that weighs 12 ounces in the air, and only eight in water? — Does flint glass vary in its specific gravity? — How is the specific gravity of quicksilver to be found, and what is it if a given quantity weigh 480 penny-weights in air and only 445 in water? — How can the specific gravity of precious stones and other small fragments of bodies be found?

CONVERSATION XIII.

OF THE METHODS OF FINDING THE SPECIFIC GRAVITY OF BODIES.

Charles. I have endeavoured to find out the specific gravity of this piece of beech-wood; but, as it will not sink in the water, I know not how to do it.

Fa. It is true that we have hitherto only given rules for the finding of the specific gravity of bodies heavier than water: a little consideration, however, will enable you to discover the specific gravity of the beech. Can you contrive means to sink the beech in the water?

Ch. Yes; if I join a piece of lead, or other metal, to the wood, it will sink.

Fa. The beech I find weighs 660 grains in the air. I will attach to it an ounce, or 480 grains of tin, which in water loses 51 grains of its weight. In air the weight of the wood and metal, taken together, is 1140 grains; but in water they weigh but 138 grains: 138 taken from 1140 leave 1002, the difference between the weights in air and in water.

Ch. I now see the means of finding what I want. The whole mass loses 1002 grains by immersion, and the tin, by itself, lost in water 51 grains: therefore the wood lost 951 grains of its weight by immersion: and 660 grains, the weight of the beech in air, divided by 951, which it may be said to lose by immersion, leaves in decimals, for a quotient, ·694.

Fa. Therefore, making water the standard equal to 1, the beech is ·694, or nearly $\frac{7}{10}$ths of 1: that is, a cubic foot of water is to a cubic foot of beech as 1000 to 694; for the one weighs 1000 ounces, and the other 694 ounces.

Em. It seems strange that a piece of wood weighing but 660 grains in air, should lose of its weight 951 grains.

Fa. You must, in this case, consider the weight necessary to make it sink in water; which must be added to the weight of the wood.

I will now endeavour to make the subject easier by a different method.

Fig. 22.

This small piece of elm I will place between the little tongs, which are nicely balanced on the beam, fig. 20. The elm weighs 36 grains. To detain it under water, I must hang 24 grains to the end of the lever on which the tongs are fixed: then, by the rule of three, I say—as the specific gravity of the elm is to the specific gravity of water, so is 36, the weight of the elm, to 60, the weight of the elm and the additional weight required to sink it in water, or as 60 : 36 : : S. G. W : S. G. E.

Em. You have not obtained the specific gravity of the elm, but only a portion of it.

Ch. But three terms are given; because the water is always considered as unity, or 1; therefore the specific gravity of the elm is $\frac{36 \times 1}{60} = \cdot 6$.

Em. I do not yet comprehend the reason of the proportion assumed.

Fa. It is very simple. The elm is lighter than the water; but, by hanging weights to the side of the balance, to which it is attached in order to detain it just under water, I make the whole exactly equal to the specific gravity of the water, by thus making it evident that the comparative gravity of the elm is to that of the water as 36 to 60.

Try this piece of cork in the same manner.

Em. It weighs $\frac{1}{2}$ an ounce, or 240 grains, in air; and to detain the cork and tongs just under water, I am obliged to hang 2 ounces, or 960 grains, of lead on the lever: therefore the specific gravity of the cork is to that of the water as 240 is to 1200; and 240 divided by 1200 give the decimal ·2.

Fa. Then the specific gravity of water is 5 times greater than that of cork.

Ch. We have now obtained the specific gravities of water, beech, elm, and cork, which are as 1, ·7, nearly ·6 and ·2.

Fa. You now understand the methods of obtaining the specific gravity of all solids, whether lighter or heavier than water. In making experiments upon light and porous woods, the operations must be performed as quickly as possible, to prevent the water from getting into the pores.

Ch. And you have likewise shown us a method of getting the specific gravity of fluids, by weighing certain quantities of each.

Fa. I have a still better method. The rule I will give in words; which you shall illustrate by examples.

"If the same body be weighed in different fluids, the "specific gravity of the fluids will be as the weights lost."

Em. The body made use of, then, must be heavier than the fluids.

Fa. Certainly: this glass ball loses of its weight, by immersion in water, 803 grains; in milk it loses 831 grains; therefore the specific gravity of the water is to that of milk as 803 to 831. Now, a cubic foot of water weighs 1000 ounces. What will be the weight of the same quantity of milk?

Em. As 803 : 831 : : 1000 : $\frac{1000 \times 831}{803} = 1035$ ounces nearly.

Fa. Now, Charles, tell me the specific gravity of the spirit of wine I have here.

Ch. The glass loses in water 803 grains; in the spirit of wine it loses 699 grains; therefore the specific gravity of water is to the spirit as 803 is to 699; and to find the weight of a cubic foot of the spirit, I say, as 803 : 699 : : 1000 : $\frac{1000 \times 699}{803} = 870$ ounces.

Fa. You may now deduce the method of comparing the specific gravities of solids one with another, without making a common standard.

Here is an ounce of lead and another of tin: I may weigh them in any fluid whatever. In water the lead loses by immersion 42 grains, and the tin 63 grains.

Em. Is the specific gravity of the lead to that of the tin as 42 to 63?

Fa. No: "the specific gravities of bodies are to one another *inversely* as the losses of weight sustained:" therefore the specific gravity of the lead is to that of the tin as 63 to 42; or if a block of lead weigh 63 pounds, the same sized block of tin will weigh 42 pounds only.

Ch. I think I see the reason of this: the heavier the body, the less it loses of its weight by immersion: therefore, of two bodies whose absolute weights are the same (that is, each weighing an ounce, pound, &c.) the one which loses least of its weight will be the most specifically heavy.

Fa. Exactly so; for the specific gravity of bodies is as their density, and their densities are inversely as the weights they lose by immersion; that is, the body that is most dense will lose the least in water.

Ch. How are the specific gravities of gaseous fluids estimated?

Fa. The specific gravities of gaseous fluids are estimated in terms of atmospheric air, as other substances are by water. The difference between the weights of a flask when exhausted of air by means of the air-pump, and when filled with the gas gives the weight of the gas which it contains: but experiments of this nature require great caution, for they are considerably influenced by the variations of the temperature and pressure of the air.

QUESTIONS FOR EXAMINATION.

How can I find the specific gravity of bodies that are lighter than water? — What is the specific gravity of a piece of beech-wood that weighs 660 penny-weights, to which when a piece of metal weighing 480 penny-weights is annexed, it loses by being immersed in water 51 penny-weights? — Explain the mode adopted in finding the specific gravity of a piece of elm or other wood by means of fig. 22. — Make the experiment with cork. — What precautions are necessary in making the experiments upon porous bodies? — Is there any other rule for finding the specific gravity of fluids?—Explain this by

an experiment in water and milk. — A piece of glass plunged in water loses of its weight 803 grains; but in spirit of wine it loses 699 grains: what are the specific gravities of the two fluids? — Can you with equal bulks of different bodies obtain their specific gravities, and how is it done? — Are the specific gravities in proportion to the weights lost by immersion in water? — What is the reason of the rule that you have now given me?

CONVERSATION XIV.

OF THE METHODS OF OBTAINING THE SPECIFIC GRAVITY OF BODIES.

Father. As I have shown you, my dear children, the methods of finding the specific gravity of almost all kinds of bodies, it will be proper in this lesson, and one or two others, to show you the practical utility of this part of science.

Em. To whom are we indebted for the discovery of this mode of performing these operations?

Fa. To that most celebrated mathematician of antiquity, Archimedes, who found that a solid plunged in a fluid displaces a quantity of the fluid equal to its bulk.

Ch. Was he not slain by a common soldier, at the siege of Syracuse?

Fa. He was; to the great grief of Marcellus, the Roman commander, who had ordered that his house and person should be respected: but the philosopher was too deeply engaged in solving some geometrical inquiries to think of seeking that protection which even the enemy intended for him. This was upwards of 200 years B.C.

Em. Had he then so high a reputation as to induce the general of a besieging army to give particular orders for his preservation?

Fa. His celebrity was so great among the literati of Rome, that his tragical end caused more real sorrow than the capture of the whole island of Sicily caused joy.

We are informed by history that the wisdom of Archimedes suspended for a long time the fate of Syracuse. His inventions destroyed multitudes of the Roman army, as well as their ships: and it is added that he made use of burning glasses, which, at the distance of some hundreds of yards, set the Roman vessels on fire.*

* This subject will be considered more at large in our Conversations on Optics.

But to return to our subject. To Archimedes the world is indebted for the discovery, "That every body heavier than its bulk of water loses so much of its weight, by being suspended in water, as is equal to the weight of a quantity of water equal to its bulk."

Em. How did he make the discovery?

Fa. Hiero, king of Syracuse, who was the friend and patron of this great mathematician, and himself an eminent philosopher, as well as a good and virtuous prince, had given to a jeweller a certain quantity of pure gold, to make a crown for him. The monarch, when he saw the crown, suspected that the artist had kept back part of the gold.

Em. Why did he not weigh it?

Fa. He did; and found the weight right: but he suspected, perhaps from the colour of the crown, that some baser metal had been mixed with the gold, and therefore, though he had his weight, yet only a part of it was gold; the rest silver or copper. He applied to Archimedes to investigate the fraud.

Ch. Did he melt the crown, and endeavour to separate the metals?

Fa. No: that would not have answered Hiero's intentions. His object was to detect the roguery, if any, without destroying the workmanship. However, while the philosopher as intent upon the problem, he went, according to his custom, into the bath; and he observed that a quantity of water flowed over, which he thought must be equal to the bulk of his own body. He instantly conceived the means of satisfying Hiero's doubts. In raptures at the discovery, he is said to have leapt from the water and run naked through the streets of the city, shouting aloud *Eureca! Eureca!* (Ευρηκα! Ευρηκα!) "I have found it out!" "I have found it out!"

When the excess of his joy was abated, he procured two masses, one of gold, and the other of silver, each equal in weight to the crown; and having filled a vessel very accurately with water, into which he first dipped the silver mass, and observed the quantity of water that flowed over: he then did the same with the gold, and found that the quantity of water flowing over was less than before.

Ch. And from these trials was he led to conclude that the bulk of the silver was greater than that of the gold?

Fa. He was. And also that the bulk of water displaced

was, in each experiment, equal to the bulk of the metal. He then made the same trial with the crown, and found that, although of the same weight with the masses of silver and gold, yet it displaced more water than the gold, and less than the silver.

Em. Accordingly he concluded, I imagine, that it was neither pure gold, nor pure silver.

Ch. But how could he discover the proportions of each metal?

Fa. I believe we have no other facts to carry us further into the history of this interesting experiment, for no test of this kind can ever be accurate, either in solids or fluids, unless we have previously ascertained that they have undergone by chemical union no change of internal structure; for substances in composition very frequently have a different specific gravity than when separate and distinct. If, however, a piece of gold has an internal hollow filled with silver, the process of weighing in water would readily and accurately prove the presence of the two metals; but were they melted together, the specific gravity of the compound might possibly be greater or less than their separate gravities. Again, the heat or temperature of the substances at the time of the experiment must be taken into account; for heat has the property of increasing the bulk of all bodies, and consequently makes them specifically lighter, from the same quantity of matter filling a larger space; and because, moreover, different substances are expanded in different degrees by it. But to-morrow I will endeavour to explain and illustrate the matter.

QUESTIONS FOR EXAMINATION.

By what means and by whom was the method of obtaining the specific gravities of bodies discovered? — What is the axiom deduced from the discovery of Archimedes? — To what practical purpose did he apply his discovery? — Can you in your own words briefly explain the mode adopted by Archimedes in detecting the roguery of the Sicilian jeweller?

CONVERSATION XV.

OF THE METHODS OF OBTAINING THE SPECIFIC GRAVITY OF BODIES.

Emma. You are to describe to-day, Papa, the method of detecting the proportion of each metal, if two are mixed together in one mass.

Fa. Well then, suppose I take in change a guinea, which I suspect to be bad: upon trying it, I find it weighs 129 grains, which is the standard weight of a guinea. I then weigh it in water, and it loses of its weight $8\frac{1}{4}$ grains, by which I divide the 129, and the quotient is 15·6, the specific gravity of the guinea. But you know the specific gravity of the gold, in our current coin, is more than 17; and therefore I conclude that the guinea is a mixture of silver, or copper, with standard gold.

Ch. But how will you get the proportions of the two metals?

Fa. Suppose, for example, that the mass be a compound of silver and gold.—"Compute what the loss of a mass of standard gold would be; and likewise the loss which a mass of silver, equal in weight to the guinea, would sustain. Subtract the loss of the gold from that of the compound; the remainder is the ratio or proportion (not the quantity) of the silver: then subtract the loss of the compound from that of the silver; the remainder is the proportion of the gold." I will propose you an example.

What are the proportions of silver and gold in a guinea weighing 129 grains, whose specific gravity is found to be only 13·09; supposing the loss of standard gold 7·25, and that of a piece of silver, equal in weight to a guinea, 12·45, and the loss of the compound 9·85?

Ch. I first subtract the loss of standard gold, 7·25, from the loss of the compound 9·85; the remainder is 2·6. I now take the loss of the compound 9·85 from that sustained by the silver 12·45, and the remainder is also 2·6.

Fa. Then the proportions of silver and gold are equal to one another: consequently, the false guinea is half standard gold and half silver.

Here is another counterfeit guinea, which is full weight; but I know that it is composed of standard gold adulterated with copper, and its loss in water is, as you see, 8·64: now tell me the proportions of the two metals. You should, however, be informed that a piece of copper, of the weight of a guinea, would lose in water 14·65 grains.

Em. I deduct 7·25 (the loss of a guinea standard gold) from 8·64; the remainder is 1·39. I now take the loss of the compound 8·64 from 14·65 (the loss sustained by a piece of

copper equal in weight to a guinea) and the remainder is 6·01. Is not the proportion of copper to gold as 1·39 to 6·01?

Fa. Certainly. Now, by the rule-of-three, tell me the quantity of each metal.

Em. To find the weight of the copper, I add 6·01 and 1·39 together, which are the *proportional* weights of the two metals; and say, as 7·40, the sum, is to 1·39 (the *proportional weight* of copper) so is the weight of the guinea, 129 grains, to the *real weight* of copper contained in the counterfeit guinea: but $\frac{1{\cdot}39 + 129}{7{\cdot}40} = 24{\cdot}1$; therefore there is little more than 24 grains of copper in the compound.

Fa. You have found, then, that there are 24 grains of copper in this counterfeit guinea. How will you find the weight of the gold?

Em. Very easily: for if the composition be copper and gold, and there are found to be 24 grains of copper, there must be 105 of gold.

Ch. I have a question to propose, Papa. If, by chance, you take a bad guinea, how should you be able to ascertain the value it would fetch at the goldsmith's?

Fa. In this way: a piece of copper of equal weight with a guinea, loses of its weight in water 14·65 grains, 7·4 more than is lost by a standard guinea. The value of a standard guinea is 252 pence. Divide therefore 252 by 7·4, and you get 34, the number of pence that is deducted from the value of a guinea, for every grain it loses more than it would lose if it were sterling gold.

Em. In the guinea that lost 8·64, how much must be deducted from the real value of a guinea of standard gold?

Ch. I can tell that. Subtract 7·25 from 8·64, the remainder is 1·39; and this multiplied by 34 pence gives 47·26 pence, or very nearly 4 shillings; consequently that guinea is worth only 17 shillings.

Fa. Suppose the compound were silver and gold, how would you proceed in making an estimate of its value?

Ch. A piece of silver of the weight of a guinea would lose 12·45 grains; from which I deduct 7·25, and with the remainder, 5·2, I divide the value of a guinea, or 252 pence; and the quotient, 48·4 pence, or rather more than 4 shillings,

is to be deducted from the value of a guinea adulterated with silver, for every grain it loses by immersion more than standard gold.

Em. How is that, Papa? Silver is mueh dearer than copper: and yet you allow 4 shillings a grain when the guinea is alloyed with silver, and but 2*s.* 10*d.* when the mixture is made with eopper.

Fa. Beeause the speeifie gravity of silver is mueh nearer than eopper to that of gold; eonsequently, if equal quantities of silver and eopper were mixed with gold, the silver would cause a mueh less loss by immersion in water than the eopper.

As it seldom happens that the adulteration of metal in guineas is made with all eopper, or with all silver, but generally with a mixture of both, three shillings are, upon the average, allowed for every grain that the base metal loses by immersion in water more than sterling gold.

Em. There is a silver eream-jug in the parlour. I have heard Mamma say, that she did not think it was real silver. How eould she find out if she has been imposed on or not?

Fa. Go and feteh it. We will now weigh it.

Em. It weighs $5\frac{1}{2}$ ounces; but I must weigh it in water. It has lost in the water $10\frac{1}{4}$ dwts; and dividing $5\frac{1}{2}$ ounees, or 110 penny-weights by $10\frac{1}{4}$, I get for answer 10·7, the speeifie gravity of the jug.

Fa. Then there is no eause for eomplaint; for the speeifie gravity of good wrought silver is seldom more than this. I shall now present you with a

Table of Specific Gravities of Solids and Liquids at the temperature of 32° *of Fahrenheit, the density of water being* 1.

Distilled water	1·000	Zinc	7·191
Sea-water	1·020	Glass (flint)	3·200
Water of the Dead Sea	1·248	Glass (crown)	2·520
Standard gold	19·258	Ivory	1·825
Mercury	13·598	Oil (olive)	·915
Standard silver	10·474	Cork	·240
Platina	22·069	Alcohol	·835
Lead	11·352	Proof spirit	·923
Brass	8·396	Butter	·942
Copper	8·900	India-rubber (Caoutchouc)	·933
Tin	7·291	Naphtha	·847
Iron (cast)	7·248	Blood	1·053
Iron (bar)	7·788	Chalk	2·675

Coal	1·300	Wood, beech	·852
Diamond ... 3·521 to	3·550	——— box (Dutch)	1·328
Flint	2·582	——— cedar	·596
Marble	2·716	——— ebony	1·331
Milk	1·032	——— elm	·671
Sugar	1·606	——— fir	·550
Sulphur	2·033	——— mahogany	1·063
Vinegar	1·080	——— oak	1·170
Wine averages	·993		

Table of Specific Gravities of Gases and Vapours, that of Atmospheric Air being 1.

Atmospheric air	1·000	Hydrogen gas	·069
Carbonic acid gas	1·527	Nitrogen ditto	·927
Carburetted hydrogen ditto	·927	Oxygen ditto	1·111
Chlorine ditto	2·500	Sulphuretted hydrogen ditto	1·180

QUESTIONS FOR EXAMINATION.

How am I to know whether a suspected guinea be a counterfeit or not ? — Is there any means of finding out the proportions of the base and pure metal ? — Explain the same with regard to a guinea which is full weight. — How am I to ascertain the value of a counterfeit guinea, that is composed of copper and gold ? — What are the methods of estimating its worth if it be a compound of gold and silver ? — Tell me what is the average allowance for every grain that base metal loses by immersion more than sterling gold. — How can I find whether this silver cream-jug is of fair marketable silver ?

CONVERSATION XVI.

OF THE HYDROMETER.

Father. Before I describe the construction and uses of the hydrometer, I will show you an experiment or two, which will afford you entertainment, after the dry calculations in some of our former conversations.

Ch. The arithmetical operations are rather tedious, certainly, but they serve to bring to mind what we have already learnt, and at the same time show to what uses arithmetic may be applied.

Fa. You know that wine is specifically lighter than water, and that the lighter body will always be uppermost. Upon these principles I will exhibit two or three experiments. I have filled the bulb B with port wine, to the top of the narrow stem x. I now fill A with water.

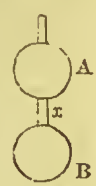

Fig. 23.

Em. The wine is gradually ascending, like a fine red thread, through the water to its surface.

Fa. And so it will continue till the water and wine have changed places.

Ch. I wonder the two liquids do not mix, as wine and water do in a common drinking glass.

Fa. It is the narrowness of the stem *x* which prevents the admixture: in time, however, this would be effected; because water and wine have what the chemists call an attraction for each other.

Here is a small bottle B with a neck three inches long, and about one-sixth of an inch wide: it is full of port wine. I will now place it at the bottom of a jar of water, a few inches deeper than the bottle is high. The wine, you observe, is ascending through the water.

Fig. 24.

Em. This is a very pretty experiment: the wine rises in a small column to the surface of the water, spreading itself over it, like a cloud.

Fa. Now reverse the experiment. Fill the bottle with water, and plunge its neck quickly into a glass of wine: the wine is taking the place of the water.

Ch. Could you decant a bottle of wine in this way, without turning it up?

Fa. I could, if the neck of the decanter were sufficiently small. The negroes in the West Indies are said to be well acquainted with this principle of hydrostatics; and they plunder their masters of rum by filling a common bottle with water, and plunging the neck of it into the bung-hole of the hogshead.

Upon the principle of lighter fluids keeping the uppermost parts of a vessel, several fluids may be placed upon one another in the same vessel without mixing: thus, in a long upright jar, three or four inches in diameter, I can place water first, then port wine, then oil, brandy, oil of turpentine, and alcohol.

Ch. How would you pour them one upon another without mixing?

Fa. This will require a little dexterity. When the water is in, I lay a piece of very thin pasteboard upon its surface, and then pour in the wine: after which I take away the pasteboard, and proceed in the same manner with the rest. Take a common goblet or drinking glass; pour water in, and then lay a thin piece of toasted bread upon the water; and

you may pour your wine upon the bread, and the two fluids will remain for some time separate.

Em. Is the toast placed there merely to receive the shock of the wine when poured in?

Fa. It is. I will now proceed to explain the principle of the *hydrometer*, an instrument contrived to ascertain with accuracy and expedition the specific gravities of different fluids, and thence the strength of spirituous liquors: the term is derived from two Greek words, *hudor* (ὑδωρ) "water," and *metron* (μετρον) "a measure."

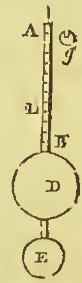
Fig. 25.

A B is a hollow cylindrical tube of glass, ivory, copper, &c., five or six inches long, attached to a hollow sphere of copper, D. To the bottom of this is united a smaller sphere, E, containing a little quicksilver, or a few leaden shot, sufficient to poise the machine, and make it sink vertically in the fluid.

Ch. What are the graduated marks on the tube?

Fa. They are degrees, exhibiting the magnitudes of the part below the surface; consequently, the specific gravity of the fluid in which it descends. If the hydrometer, when placed in water, sink to the figure 10, and in spirit of wine to 11·1, then the specific gravity of the water is to that of the spirit, as 11·1 to 10: for if the same body float upon different fluids, the specific gravity of these fluids will be to each other *inversely* as the parts of the body immersed.

Em. By *inversely* do you mean that the fluid in which the hydrometer sinks the deepest is of the least specific gravity?

Fa. Yes, I do. Here is a piece of dry oak, which if put into spirit of wine, is entirely immersed: in water, the greatest part of it sinks below the surface; but in mercury, it scarcely sinks at all. Hence it is evident that the hydrometer will sink deepest in the fluid that is of the least specific gravity.

To render this instrument of more service, a small stem is fixed at the end of the tube, upon which weights, like that at *g*, may be placed. Suppose, then, the weight of the instrument to be 10 dwts., and, by being placed in any kind of spirit it sink to a certain point, L, it will require an additional weight, suppose 1·6 dwt., to sink it to the same depth in water. In this case, the specific gravity of the water to the spirit will be as 11·6 to 10. By the addition of different weights, the specific gravity of any kind of liquor is easily

found. The point L should be so plaeed as to mark the exaet depth to whieh the instrument will sink in the liquor that has the least speeifie gravity.

Ch. But you always make the specifie gravity of water 1, for the sake of a standard.

Fa. To be sure: and to find the speeifie gravity of the spirit eompared with water at 1; I say, as 11·6 : 1 :: 10 : ·862 nearly; so that I should put the speeifie gravity of this spirit down at ·862 in a table where water was marked 1: and as a eubie foot of water weighs 1000 ounees, a cubic foot of this spirit would weigh 862 ounees; whieh is generally the standard of pure *rectified spirit.*

Em. Is this what is usually ealled spirit of wine?

Fa. No: it is the aleohol of the ehemists; one pint of whieh added to a pint of water makes a quart *nearly* of eommon spirit of wine.

Ch. You said ·862 was *generally* the speeifie gravity of aleohol. What eauses the differenee at other times?

Fa. It is not always manufaetured of equal strength: and the same fluids vary in respeet to their specifie gravity by the different degrees of heat and temperature in the atmosphere. The eold of winter eondenses the fluid, and inereases the speeifie gravity: the heat of summer eauses an expansion of the fluid, and a diminution of its speeifie gravity. The hydrometer more generally used than any other is that of Sykes, from being direeted by Aet of Parliament to be used in eolleeting the revenue of the United Kingdom from the Exeise, &e. But there is another ready method of estimating the densities of different liquids frequently praetised, by means of a set of glass beads, previously adjusted and numbered. They are thrown into any liquid, and the heavier beads sink, while the lighter float on the surfaee of the water; and the bead approaehing nearest to the density of the liquid will remain buoyant, either upon the surfaee or under it, in any position it may be plaeed, and upon this bead is the number, in thousandth parts, indieating the speeifie density of the liquid.

Em. You said just now that a pint of water added to a pint of aleohol made *nearly* a quart of spirit of wine: surely two pints make a *full* quart.

Fa. Indeed they will not. A pint of water added to a pint of water will make a quart; and a pint of spirit added to

a pint of spirit will make a quart; but mix a pint of spirit with a pint of water, and there is a certain chemical union or penetration between the particles of the two fluids, that diminishes the volume. This subject we shall resume in our chemical conversations; but I will see how far you have understood the nature of specific gravity, by asking you a question or two.

Now, as in the course of these six conversations on the specific gravities of bodies, you have witnessed a number of experiments, what are the general deductions arising in your mind from them?

Ch. I have learned that if a solid be immersed in several fluids, the weights which it loses in those fluids are as the specific gravities of the fluids: for each weight answers to a particular bulk of each particular fluid.

Fa. What is the *absolute* gravity of any substance?

Ch. That is only to be found by weighing it in a vacuum; although its comparative gravity in the air is commonly taken for its absolute gravity.

Fa. Do all solids that float upon, or are suspended in any fluid, communicate their gravity to the whole fluid?

Ch. They do: and the pressure upon that part of the bottom which lies directly under the solid is not greater than upon any other part.

To what purposes is the hydrometer applied?

Fa. It is used in breweries and distilleries, to ascertain the strength of their different liquors: and by this instrument the excise-officers gauge the spirits, and thereby determine the duties to be paid to the revenue.

It does not appear to be used so much as formerly: for if the liquors differ considerably in specific gravity, they require an increase in the limits of graduation. Thus, the hydrometer adapted to spirits will swim in water with part of the ball above the surface; and if it be adapted to water, it will not swim in spirits at all. This may be remedied, however, either by lengthening or widening the tube: but the first is inconvenient, and the latter would make the graduations so short as to render them of little use.

Ch. Is this instrument applicable to finding the specific gravity of solids as well as fluids?

Fa. It appears that Mr. Nicholson, as described in his

"Introduction to Natural Philosophy," made an attempt to adapt it to solids; and it was found to be sufficiently accurate to give weights true to less than one-twentieth of a grain. He observed at the same time that experiments concerning specific gravities in general, are more difficult to be made with accuracy than authors in general seem to imagine; as, in water, a few degrees of difference of temperature will change the figures; and in different specimens of the same kind of wood the specific gravities will also vary, as will metals cast out of the same melting, if cooled more or less quickly. The latter are also altered by hammering.*

QUESTIONS FOR EXAMINATION.

Explain the experiment intended to be exhibited by figs. 23 and 24. — By what means are the slaves in the West Indies said to plunder their masters of rum? — Can fluids of different specific gravities be placed one upon another without mixing? — For what purposes is the hydrometer used? — Explain its structure by means of fig. 25. — How is it graduated? — What is the meaning of the word *inversely* when applied to this subject? — What is the difference between spirit of wine and alcohol? — Will a pint of water and a pint of alcohol make a quart? if not, what is the cause? — In what trades is the hydrometer used?

CONVERSATION XVII.

OF SWIMMING.

Father. I think, from the time we have spent in considering the specific gravity of different bodies, you will be at no loss to account for a variety of circumstances that will present themselves to your attention in the common concerns of life. Can you, Emma, explain the theory of floating vessels?

Em. All bodies whatever that float on the surface of the water, displace as much fluid as is equal in weight to the weight of the bodies: therefore, in order that a vessel may keep above water, it is only necessary to take care that the vessel and its cargo, passengers, &c. should be of less weight than the weight of a quantity of water equal in bulk to that part of the vessel which it will be safe to immerge in the water.

Fa. Salt water (that is, the water in the sea) is specifically heavier than fresh or river water.

* Nicholson. Intr. to Nat. Philos.

Ch. Then the vessel will not sink so deep at sea as it does in the Thames.

Fa. Certainly not. If a ship be laden at Sunderland, or any other sea-port, with as much coals or corn as it can carry, it will come very safely till it reach the fresh water in the Thames; and there it will infallibly go to the bottom, unless some of the cargo be taken out.

Em. How much heavier is sea water than fresh?

Fa. About one thirtieth part; as you will see by looking at the table of specific gravities previously referred to (in Conversation XV.); and that knowledge would be a guide to the master of a vessel, who was bent upon freighting it as deeply as possible.

Ch. In bathing I have often tried to swim; but have not pet been able to accomplish the task. Is my body specifically heavier than the water?

Fa. By some very accurate experiments made by Mr. Robertson, the late librarian of the Royal Society, upon ten different persons, the mean specific gravity of the human body was found to be about $\frac{1}{9}$th less than that of common river water.

Ch. Why, then, do I sink to the bottom? I ought to swim like wood on the surface.

Fa. Though you are specifically lighter than water, yet it will require some skill to throw yourself into such a position as to cause you to float like wood.

Ch. What is that position?

Fa. Dr. Franklin, who was a great swimmer, and gave lessons in the art, when he first arrived in London as a journeyman printer, recommends a person to throw himself in a slanting position on his back; his whole body, except the face, being kept under water.

Unskilful persons, in the act of attempting this, are apt to plunge about and struggle: by which means they take water in at their mouths and nostrils, which of itself would soon render them as heavy or heavier than the water. Moreover, the coldness of the stream tends to contract the body: and, perhaps, fear has the same tendency. All these things put together will easily account for a person sinking in the water. Some persons, however, find great difficulty, even under the instruction of the best of swimmers, to keep themselves afloat.

Indeed I have seen a great many attempts made without success.

Ch. From what cause, Papa, do you conceive that this inability arises?

Fa. Some attribute it, as I have just said, to fear: but my opinion is, that it very frequently depends on the conformation of the body, as in the case of wood; some bodies being naturally more buoyant than others.

Em. But if a dog or a cat be thrown into the pond, it seems as terrified as I should be in a like situation; yet they never fail of making their way out by swimming.

Fa. Of all land animals, man is, probably, the most helpless in water. The brute creation swim naturally: the human race must acquire the art by practice. In other animals the trunk of the body is large, and their extremities small: in man, the arms and legs are small in proportion to the bulk of the body; but the specific gravity of the extremities is greater than that of the trunk; consequently it will be more difficult for man to keep above water than for four-footed animals: besides, the act of swimming seems more natural to them than to us, as it corresponds more nearly to their mode of walking and running than to ours.

Ch. I will try, the next time I bathe, to throw myself on my back, according to Dr. Franklin's directions.

Fa. Do not forget to make your experiments in water that is not so deep as your height, by at least a foot, unless you have an experienced person with you: because an unsuccessful experiment in that element, where it is but a little out of your depth, may be the last you will make. And neither your sister nor I can spare you yet.

Ch. I once jumped into a part of the New-River, which did not appear to me to be deeper than you mentioned; and I found it was over my head: but there were several persons there who soon put me in shallower water.

Fa. It is not so generally known as it ought to be, that the depth of a clear stream of water is always one-fourth part greater than it appears to be.*

Ch. If the river appear to be only three feet deep, may I reckon upon its being full four feet?

* The reason of this deception will be explained in our conversations on Optics.

Fa. You may estimate it in this manner. Remember also that if a person sink slowly in water ever so deep, a small effort will bring him up again; and if he be then able to throw himself on his back, keeping only his face above water, all will be well: but if, instead of this, he become alarmed, and, by struggling, throw himself so high above the water that his body does not displace so much of it as is equal to its weight, he will sink with an accelerated motion. A still stronger effort, which the sense of danger will produce, may bring him up again; but, in two or three efforts of this kind, his strength fails, and he sinks to rise no more alive.

Em. Is it the upward pressure which brings up a person that is at a considerable depth in the water?

Fa. It is: this upward pressure balances the weight of water which he sustains, or he would be crushed to pieces by it.

Cork an empty bottle ever so well, and with weights plunge it down a hundred yards into the sea, and the pressure of the water will force the cork into the bottle.

Ch. I must, at all events, learn to swim.

Fa. I hope you will, and well too; it may be the means of saving your own life, and rescuing others who are in danger of drowning. But let me observe to you, that the head, legs, and arms are considered specifically heavier than fresh water, though the body is not; and generally speaking an eleventh part of the weight of the body remains above the surface in fresh water, and a tenth in salt-water. It is difficult, therefore, to keep the mouth and nostrils above water; yet if the body be put into a walking position, and the head leaned back upon the water, so as to raise the chin above the level of the forehead, the mouth and nostrils are perfectly free for respiration; and bear in mind that the arms and hands must be under water if you wish to keep the head above; for the arms and head exceeding a tenth of the weight of the body, cannot be above water at the same time; it has even been said that if the arms and hands are kept under water, it would be impossible to sink. The grand thing is to have confidence, and to be fully persuaded of the natural buoyancy of the body. The safest method of swimming is the upright, recommended by Mr. Bernardi, yet it is not the swiftest, but speed must give way to security.

QUESTIONS FOR EXAMINATION.

Can you explain the theory of floating vessels? — Will a vessel sink deepest in salt water or in fresh? — Is there any danger of loading a vessel too heavily that rides in the sea, and which has to come into fresh water? — What is the difference of densities between sea and fresh water? — Is the human body lighter or heavier than fresh water? — What makes a person sink in water? — What method does Dr. Franklin recommend to a person to learn to swim? — Why do all quadrupeds swim? — What risk do incautious bathers run, and from what cause? — How much deeper is a clear stream than it appears to be? — What is the cause of a person being drowned? — By what means is a person who falls into the water brought up again from the bottom?

CONVERSATION XVIII.

OF THE SYPHON.

Fig. 26.

Father. This bent tube is called a Syphon, or more correctly spelled *siphon*, as it is a Greek word (σιφων) meaning "a hollow body, reed, tube," &c.; and is used to draw off water, wine, or other liquids from vessels which it would be inconvenient to move from the place in which they stand.

Ch. I do not see how it can draw liquor out of any vessel. Why is one leg longer than the other?

Fa. I will first show you how the operation is performed, and then endeavour to explain the principle.

I fill the tube E D C with water, and then placing a finger on E, and another on C, I invert the tube, and immerse the shorter leg into a jar of water: now, having taken my fingers away, you see that the water runs over in a stream.

Em. Will it continue to flow over?

Fa. Yes, until the water in the vessel sinks as low as E, the edge of the syphon.

Ch. Is this accounted for by pressure?

Fa. To the pressure or weight of the atmosphere we are indebted for the action of the syphon, pumps, &c. At present you must take it for granted that the air which we breathe, though invisible, has weight, and that the pressure occasioned by it is equal to about 14 or 15 pounds upon every square inch.* The surface of this table is equal to about six

* If any of my young readers are unwilling to admit this assertion without proof, they must be referred to the beginning of these dialogues for a complete demonstration of the fact.

square feet, or 864 square inches, and the pressure of the atmosphere upon it is equal to at least 12096 pounds.

Em. How does the pressure of the air cause the water to run through the syphon?

Fa. The principle of the syphon is this: the two legs are of unequal length; consequently the weight of water in the longer leg is greater than that in the shorter, and therefore will, by its own gravity, run out at C, leaving a vacuum from D to E, unless the pressure of the atmosphere on the surface of the water in the jar force it up the leg D E, and thus continually supply the place of the water in D C.

Ch. But, since the pressure of fluids acts in all directions, is not the upward pressure of the atmosphere against C, the mouth of the tube, equal to the downward pressure on the surface of the water?

Fa. The pressure of the atmosphere may be considered as equal in both cases. But these equal pressures are counteracted by the pressures of the two unequal columns of water, D E and D C. And since the atmospheric pressure is more than sufficient to balance both these columns of fluid, that which acts with the less force, (namely, the column D E,) will be more pressed against D C than D C is against D E at the vertex D; consequently the column D E will yield to the greater pressure, and flow off through the orifice C.

Em. Would the same thing happen if the outer leg, D C, were shorter than the other?

Fa. If D C were broken off, at B, even with the surface of the water, no water would run over: or if it were broken off anywhere lower than B, it would only run away till the surface of the fluid descended to a level with the length of the outer tube, because then the column D E will be no more pressed against D C than D C is against D E, and consequently the syphon will empty itself; the water in the outer leg will run out at the lower orifice, and that in the inner will fall back into the jar.

Ch. In decanting a bottle of wine, are you obliged first to fill the syphon with liquor, and then invert it?

Fa. No: either a small pipe is fixed to the outer leg of the syphon, by which the air is drawn out of it by the mouth; or the mouth is applied to the orifice of the outer leg; and the short leg having been previously immersed in the wine, the fluid will follow the air, and run out til the bottle is

empty; as long as the tube continues full, no air can gain admittance, and the liquor flows on till it is all expended. Whichever mode, however, is adopted, for water the highest part of the syphon must not exceed 34 feet above the reservoir, and for mercury not more than 30 inches, because the presence of the atmosphere will not support a greater height of water, or of mercury.

Fig. 27.

The syphon is sometimes disguised for the sake of amusing young people. Tantalus's Cup is of this kind. The longer leg of the syphon passes through, and is cemented into the bottom of the cup: if water be poured into the cup, so as not to stand so high as the bend of the tube, the water will remain as in any common vessel; but if it be raised over the bended part of the syphon, it will run over, and continue to run till the vessel is emptied. Sometimes a little figure of a man, representing Tantalus, conceals the syphon; so that Tantalus, as in the fable, stands up to his chin in water, but is never able to quench his thirst; for, just as it comes to a level with his chin, it runs out through the concealed syphon.

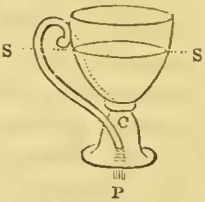

Fig. 28.

This is another kind of Tantalus' cup; but the syphon is concealed in the handle; and when the water in the cup, which communicates with the shorter leg at c, is raised above the bend of the handle, it runs out through the longer leg at P, and so continues till the cup is empty. This cup is often made to deceive the unwary, who, by taking it up to drink, cause the water, which was, while at rest, below the bend of the syphon, to run over; and then there is no means of stopping the stream till the vessel is empty.

Ch. I have frequently seen, at the doors of public houses, large hogsheads of spirits in carts or wagons, and persons drawing off the contents by means of an instrument like a syphon.

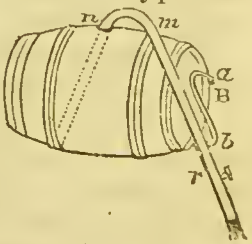

Fig. 29.

Fa. That is called a distiller's crane or syphon. B represents one of these barrels with the crane at work from the bung-hole *n*. The longer leg, *m r*, is about three feet long, with a stop-cock near the middle, which must be shut, and then the shorter leg is immersed in the liquor.

Em. Then, by the upward pressure of the fluid, the air in the short leg is forced into the other.

Fa. And the cock being shut, it cannot escape, but will be very much condensed. If, then, the cock be suddenly opened, the condensed air will rush out, and the pressure of the air on the liquor in the vessel will force it over the bend of the syphon, and cause it to flow off in a stream, as the figure represents. If, however, the barrel be not full, or nearly so, then it is necessary to draw the air out of the syphon by means of a small tube, *a b*, fixed to it.

By the principle of the syphon we are enabled to explain the nature of intermitting springs.

Em. What are these, Papa?

Fa. They are springs, or rather streams, that flow periodically. A figure will give a clearer idea of the subject than many words without it. Let G F C represent a cavity in the bowels of a hill or mountain, which may be considered as the reservoir or vessel of liquor to be drawn off, from the bottom of which, C, proceeds the irregular channel or duct, C E D, forming a sort of natural syphon, having its shortest leg opening into the reservoir, and its longest at the surface of the earth where the spring appears. Now, as this cavity fills, by means of rain or melted snow draining through the pores of the ground, the water will gradually rise in the leg C E, till it has attained the horizontal level *h h*, when the spring will begin to flow through the leg E D, upon the principle of the equilibrium of fluids, and continue to increase in the quantity discharged as the water rises higher, till a full stream is sent forth, and then, by the principle of the syphon, it must continue to flow till the water sinks to the level *i i*, when the air will rush into the syphon, and stop its motion.


Fig. 30.

Ch. And being once brought so low, it cannot run over again till the cavity is full of water, or, at least, up to the level *h h*, which, as it is only supplied by the draining of the water through the ground, must take a considerable length of time. Is it by reason of the reservoir being imperfectly supplied that they are called intermitting springs?

Fa. It is. Mr. Clare, in his treatise "On the Motion of Fluids," illustrates this subject by referring to a pond at Gravesend, out of which the water *ebbs* all the time the tide is coming in to the adjacent river, and runs in while the tide is going out. Another instance mentioned by the same author, is a spring in Derbyshire, called the Wedding-well, which, at certain seasons, sends forth a strong stream, with a singing noise, for about three minutes, and then stops again. At Lambourn, in Berkshire, there is a brook which, in summer, carries down a stream of water sufficient to turn a mill; but during the winter there is scarcely any current at all. There is also an intermitting spring at Laywell, near Torbay, in Devonshire, having many superstitious notions connected with it, which are prettily described by Dr. Atwell in the "Philosophical Transactions," No. 424.

In intermitting springs, the periodical returns of the flowing and cessation will be regular, if the filling of the reservoir be so; but the interval of the returns must depend on the quantity of water furnished by the springs.

Ch. What is the Wurtemburg syphon, Papa?

Fa. It is a syphon made with both branches equal, and turned up at both ends, so that as long as the extremities are kept on the same level, it will continue always full and ready for use. It takes its name from having been first used at Wurtemburg.

Can you tell me now, Charles, from what we have been considering, whether there are limits to the action of the syphon?

Ch. Yes; for I find that if the perpendicular action of the syphon, from its bend to the surface of the water, be 34 feet, or more, the instrument cannot be filled by suction, or by any other method of exhausting the air; and if it be filled first, the water will separate at the bend, part of it running out at each orifice; because, when such a syphon is full, the weight of the water in each leg is greater than the pressure of the atmosphere.

Fa. You are quite correct, Charles; and from the same principles, you will perceive, by and by, when we come to speak of Pumps, the reason of the construction and working of common pumps, and why they cannot raise water higher than about 34 feet.

QUESTIONS FOR EXAMINATION.

What is the syphon intended for?—How does it act?—To what is the action of pumps and other hydraulic machines to be attributed?—How is the pressure of the air estimated?—By what means does the pressure of the air make the syphon act?—Explain this to me by the assistance of the figure.—Explain the principle upon which a bottle of wine, &c., is decanted by the syphon?—How is the Tantalus's cup explained?—Explain by the figure in what manner the distiller's crane acts.—How is the nature of intermitting springs accounted for?—Can you explain the theory by a reference to the figure?

CONVERSATION XIX.

OF THE DIVING BELL.

Father. Take this ale-glass, and thrust it with the mouth downwards into a glass jar of water, and you will perceive that but very little water will enter into it; the greater portion of the space remaining empty, or rather only filled with air, and any object placed in this would continue perfectly dry though completely surrounded by water.

Ch. The water does not rise in it more than about a quarter of an inch. If I properly understand the subject, the air, which filled the glass before it was put in water, is in quantity the same, but is now eompressed into the smaller space; and it is this body of air that prevents more water getting into the glass.

Fa. That is the reason: for if you tilt the glass a little on one side, a part of the air will escape in the form of a bubble; and then the water will rise higher in the glass: and this compression of the air is more or less in proportion to the depth to which it is made to descend.

Upon this simple principle an apparatus has been invented, by whieh people have been able to walk about at the bottom of the sea with as much safety as upon the surface of the earth. The first invented machine of this kind was subject to two great disadvantages; one was that the men had to work in the water, which the eompressibility of the air admitted into the bottom of the bell; and the other was, that the air within the bell, by repeated respiration, soon beeame mephitic and unfit to sustain life, so that it had continually to be drawn up to admit fresh supplies; it was, therefore, very little employed

till Dr. Halley, more than a century ago, remedied the chief defect of the want of fresh air, and improved its construction. Who the original inventor was is not known. Beckmann, in his interesting "History of Inventions," relates the circumstance of two Greeks, at Toledo, in the sixteenth century, descending beneath the water in a machine of this principle, and in the presence of the Emperor Charles V., and many thousand spectators. It is said to have been obscurely mentioned by Aristotle, B.C. 325, and to have been first used in Europe in A.D. 1509. It was called the Diving Bell, and was suspended by a chain from a ship above it.

Ch. Was it made in the shape of a bell?

Fa. It was: and as great strength was required to resist the pressure of the water, he caused it to be made of copper. This is a representation of it. The diameter at the bottom was five feet; that of the top three feet; and it was eight feet high. To make the vessel sink vertically in water, the bottom was loaded with a quantity of leaden balls.

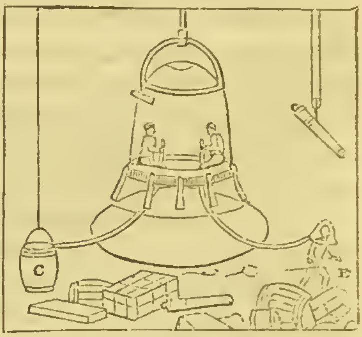

Fig. 21.

Em. It was as large as a good sized closet. But how did he contrive to get light?

Fa. Light was let into the bell by means of strong spherical glasses fixed in the top of the machine.

Ch. How are the persons who dive supplied with air?

Fa. Barrels, filled with fresh air, were made sufficiently heavy, and sent down; such as that represented by C; from which a leathern pipe communicated with the inside of the bell, and a stop-cock at the upper-part of the bell let out the foul air.

Em. The men seem to sit very contentedly under the bell: yet I do not think I should like to be with them.

Fa. Perhaps not: but the principal inconvenience which the divers experience arises from the condensation of the air in the bell, which though in the ale-glass was very trifling, yet, at considerable depths in the sea is very great, and produces a disagreeable pressure upon all parts of the body, but more particularly in their ears, as if quills were thrust into

them. This sensation does not last long; for the air, pressing through the pores of the skin, soon becomes as dense within their bodies as without; and then the sense of pressure ceases.

Em. They might stop their ears with cotton.

Fa. One of them onee thought himself as eunning as you; and, for the want of cotton, he chewed some paper, and stuffed it into his ears. As the bell descended, the paper was forcibly pressed into the cavities, and it was with great difficulty, and some danger, that it was extracted by a surgeon.

Ch. Are the divers able to remain long under water?

Fa. Yes: when all things are properly arranged, if business require it, they will stay several hours, without the smallest difficulty, employing themselves, sometimes in clearing the bottoms of harbours, sometimes in laying foundations of buildings, and at others in bringing up all kinds of materials that may have accidentally sunk, as from wrecks, &c.

Em. But how do they get up again?

Fa. They are generally let down from a ship, and, taking a rope with them, the extremity of which is attached to a bell in the vessel, they have only to pull the string, and the people in the ship draw them up.

Ch. What does the figure E outside the bell represent?

Fa. A man detached from the bell, with a kind of inverted basket made of lead, in which is fixed another flexible leathern pipe, to give him fresh air from the bell as often as he may find it necessary. By this method a man may walk to the distance of 80 or 100 yards from the machine.

Em. It is to be hoped his comrades will not forget to supply him with air.

Fa. If his head be a little above that part of the bell to which the pipe communicates, he can, by means of a stop-eock, assist himself as often as he requires a new supply; and that man is always best helped who can help himself.

Ch. I doubt not but that is a right principle. In the present case, I am sure, it would be exceedingly wrong to depend on another for that which might be done by oneself. Has the Diving Bell been applied to any very useful purposes?

Fa. By means of this invention, as I have before observed, a great number of valuable eommodities have been recovered

from wrecks of ships, though at great depths in the sea. Some very heavy and valuable articles have lately been recovered by it from the Royal George, a first-rate man-of-war, sunk by accident more than fifty years ago at Spithead.

QUESTIONS FOR EXAMINATION.

Upon what principle is the diving-bell made?—Explain the structure of that represented in Fig. 31.—In this machine how are divers supplied with air?—What sensations do divers feel under water?—How are divers brought up?—To what purpose is the diving-bell applied?

CONVERSATION XX.

OF THE DIVING BELL—*continued.*

Father. You see how, by this contrivance, the parts of wrecked vessels and their cargoes are saved from the devouring ocean; and by what means people are enabled to pursue the business of pearl and coral fishing.

Em. Have there been no accidents attending this business?

Fa. There are very few professions, however simple, the exercise of which, either through carelessness or inattention, is not attended with danger. The diving-bell proved fatal to Mr. Spalding and an assistant, who went down to view the wreck of the Imperial East-Indiaman near Ireland. They had been down twice; but on descending the third time, they remained about an hour under water, and had two barrels of air sent down to them; but on signals from below not being again repeated, after a certain time they were drawn up by their assistants, and both found dead in the bell. This accident happened by the twisting of some ropes, which prevented the unfortunate sufferers from announcing their wants to their companions in the ship. Mr. Day also perished at Plymouth in a diving-bell of his own construction, in which he was to have continued, for a wager, twelve hours, one hundred feet deep in water.

Ch. Did these accidents put an end to the experiments?

Fa. By no means, but have led to several improvements in the structure and use of the machine. After the improvements of Mr. Spalding, Mr. Smeaton, in 1788, in order to

carry on the operations contemplated in Ramsgate harbour, very successfully made use of a square cast-iron chest, the weight of which, 50 cwt., was heavy enough to sink itself. It was $4\frac{1}{2}$ feet in height, the same number of feet in length, and 3 feet wide; which of course afforded sufficient room for two men at one time to work under it.

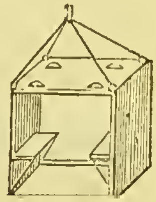

Fig. 32.

Em. What are those round things at the top of the machine?

Fa. They are four strong pieces of glass, to admit the light. The great advantage which this had over Dr. Halley's bell was, that the divers were supplied with a constant influx of air, without any attention of their own, by means of a forcing air-pump, worked in a boat upon the surface of the water over them.

Diving-bells have latterly been much used, especially by Mr. Rennie, in the construction of the various harbours he projected; and they have also been successfully employed in deepening the Clyde between Glasgow and Greenock, and improving the navigation of the river.

Ch. That is not represented in the plate.

Fa. Look to the next figure, which is a diving machine of a different construction, invented by the very ingenious lecturer, Mr. Adam Walker,*

This machine is of the shape of a conical tub; but little more than one-third as large as Mr. Smeaton's. The balls at the bottom are composed of lead, sufficiently heavy to make it sink of itself: a bent metal tube, *a b c*, is attached to the outside of the machine with a stop-cock, and a flexible leathern tube to the other end, *c*: this tube is connected with a forcing air-pump, *d*, which abundantly supplies the diver with fresh air.

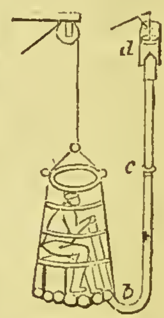

Fig. 33.

Em. Can he move about with the machine?

Fa. Most readily; for the pressure of the water being equal on all sides, he meets with very little resistance; and the ropes and leathern tube being flexible, he can, with the machine over his head, walk about several yards, in a perpendicular posture; and thus, having a more ready access to

* See Walker's System of Natural Philosophy, 2 vols. 4to.

objects under water than in a cumbrous bell, he can easily fasten ropes to them, and perform what may be necessary nearly as well as on dry land. Mr. Walker says, that the greatest part of the valuables saved from the rich ship Belgioso was taken up by this bell. The following anecdote, given by this gentleman, may prove interesting to my younger readers.

"As the diver had plenty of air to spare, he thought a candle might be supported in the bell, to enable him to descend by night. He made the experiment, and presently found himself surrounded by fish; some very large, and many such as he had never seen before. They sported about the bell, and smelt at his legs, as they hung in the water. This rather alarmed him, for he was not sure but some of the larger ones might take a fancy to him: he therefore rang his bell to be taken up, and the fish accompanied him with much good nature to the surface."

But *diving* is also carried on without the Diving-bell by means of certain mechanical apparatus to supply the diver with fresh air and light, and leave him the free use of his arms and legs. Borelli contrived a diving bladder, of brass or copper, two feet in diameter, to contain the diver's head, which was fastened to a goat-skin covering. A Mr. Deane, on the west coast of Scotland, improved on this, by constructing a copper helmet, furnished with all necessary apparatus for breathing and seeing, and with a water-proof dress, so that the diver could remain five or six hours under water perfectly dry, and thus be enabled to bring up considerable treasure from the bottom of the sea.

QUESTIONS FOR EXAMINATION.

Have pearl and coral fishing been attended with accidents?—What is the structure of Mr. Smeaton's diving-machine?—Explain the nature of the one invented by Mr. Adam Walker.

CONVERSATION XXI.

OF PUMPS.

Father. Here is a glass model of a common household-pump, which acts by the pressure of the atmosphere on the surface of the water in which it is placed.

Fig. 34.

Em. Is this like the pump below stairs?

Fa. The principle is exactly the same: *a* represents a ring of wood, or metal, with pliable leather fastened round it to fit the cylinder A. Over the whole is a valve of metal covered with leather, of which a part serves as a hinge by which the valve may open and shut.

Ch. What is a valve, Papa?

Fa. It may be described as a kind of lid or trap-door, that opens one way into a tube, but which, the more forcibly it is pressed the other way, the closer the aperture is shut: so that it admits the entrance of a fluid into the tube, but prevents its return; or permits it to escape, and prevents its re-entrance.

Attend now to the figure. The handle and rod, *r*, end in a fork, *s*, which passes through the piston, and is screwed fast to it on the under side. Below this, and over a tube of a smaller bore, as *z*, is another valve, *i*, opening upward, which admits the water to flow up, but not to run down.

Em. That valve is open now; by which we see the size of the lower tube; but I do not perceive the upper valve.

Fa. It is supposed to be shut, and in this situation the piston *a* is drawn up, and, being air-tight, the column of air on its top is removed, leaving, consequently, a vacuum in the part of the cylinder between the piston and the lower valve.

Ch. I now see the reason of lifting up the handle, to pump up the water: because the piston then goes down to the lower valve, and by its ascent afterwards the vacuum is produced.

Fa. And the closer the piston is to the lower valve, the more perfect will be the vacuum.

You know that there is a pressure of the air on all bodies, on or near the surface of the earth, equal to about 12 or 15 pounds on every square inch. This pressure upon the water in the well, into which the lower end of the pump is fixed, forces the water into the tube *z* above its level, as high as *l*.

Ch. What becomes of the air that was in that part of the tube?

Fa. You shall see the operation. I will put the model into a dish of water which now stands at a level, in the tube *z*, with the water in the dish. I draw up the piston *a*, which causes a vacuum in the cylinder A.

Em. But the valve *i* opens; and now the water has risen as high as *l*.

Fa. Because, when the air was taken out of the cylinder A, there was no pressure upon the valve *i*, to balance that beneath it; consequently the air in the tube *z* opens its valve *i*, and part of it rushes into *a*. But as soon as part of the air had left the tube *z*, the pressure of the atmosphere upon the water in the dish was greater than that of the air in the tube, and therefore, by the excess of pressure, the water is driven into it as high as *l*.

Ch. The valve *i* is again shut.

Fa. That is, because the air is diffused equally between the level of the water at *l* and the piston *a*; and therefore the pressures over and under the valve are equal: and the reason that the water rises no higher than *l* is, that the air in that space is not only equally diffused, but is of the same density as the air without. Push down the piston *a* again.

Em. I saw the valve in the piston open.

Fa. For the air between the piston and valve *i* could not escape by any other means than by lifting up the valve in *a*. I will draw up the piston.

Ch. The water has risen now above the valve *i*, as high as *m*.

Fa. I dare say you can tell the cause of this.

Ch. It is this. By lifting up the piston, the air that was between *l* and the valve *i* rushed into A, and the external pressure of the atmosphere forced the water after it.

Fa. You are right. And now that portion of air remains between the surface of the water *m* and the piston. The next time the piston is forced down, all the air must escape, the water will get above the valve in the piston, and, in raising it up again, it will be thrown out of the spout.

Em. Will the act of throwing that out open the lower valve again, and bring in a fresh supply?

Fa. Yes: every time the piston is elevated, the lower valve rises, and the upper valve falls; but every time the piston is depressed, the lower valve falls, and the upper one rises.

Em. This method of raising water is so simple and easy, that I wonder people should take the trouble of drawing

water up from deep wells, when it might be obtained so much easier by a pump.

Fa. I was going to tell you, that the action of pumps, so beautiful and simple as it is, is very limited in its operation. If the water in the well be more than 32 or 33 feet from the valve *i*, you may pump for ever, but without any effect.

Ch. That seems strange; but why 33 feet in particular?

Fa. I have already told you that it is the weight of the atmosphere which forces the water into the vacuum of the pump: now, if this weight were unlimited, the action of the pump would be so likewise: but the weight of the atmosphere is only about 14 or 15 pounds on every square inch; and a column of water, of about 33 or 34 feet in height, and whose surface is one square inch, weighs also 14 or 15 pounds.

Ch. Then the weight of the atmosphere would balance or keep in equilibrium only a column of water of 33 or 34 feet high, and consequently could not support a greater column of water, much less have power to raise it up.

Em. A pump, then, would be of no use in the deep wells which we saw near the coast in Kent.

Fa. None at all: the piston of a pump should never be set to work more than 28 feet above the water, because, at some periods, the pressure of the atmosphere is so much less than at others, that a column of water, something more than 28 feet, will be equal to the weight of the air. In fact, although in theory the limit of the height to which water may be raised by the sucking pump from the surface of the fluid to the highest point is 34 feet, which is the height of a column of water that balances the pressure of the atmosphere, yet from the impracticability of making the apparatus perfectly air-tight, it cannot be raised above 28 feet in pumps of ordinary construction.

The pump we have been describing is called the *Sucking Pump;* there are two other kinds, called the *Forcing Pump,* and the *Chain Pump,* which shall form the subject of our next conversation.

QUESTIONS FOR EXAMINATION.

Can you show by Fig. 34 how the pump acts?—To what depth is the action of the suction-pump confined?—Why is a pump useless in wells more than 33 feet deep?—To be sure of the action of a pump, how far from the water should the piston be set?

CONVERSATION XXII.

OF THE FORCING-PUMP — FIRE ENGINE—ROPE-PUMP — AND HYDRAULIC-PRESS.

Charles. Why is this called the forcing-pump?

Fa. Because it not only raises the water into the barrel like the common pump, but afterwards forces it up into the reservoir K K.

Em. How is that operation performed, Papa?

Fa. The pipe and barrel are the same as in the other pump; but the piston has no valve: it is solid and heavy, and made air-tight, so that no water can get above it.

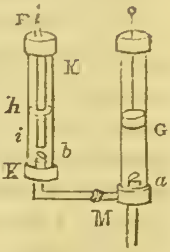

Fig. 35.

Ch. Does the water come up through the valve *a*, as it did in the last?

Fa. By raising up the piston, or, as it is generally called, the plunger, G, a vacuum is made in the lower part of the barrel, into which, by the pressure of the air, the water rushes from the well, as you shall see.

Em. And the valve is shut down.

Fa. The water not being able to go back again, and being a fluid that is nearly incompressible, when the plunger is forced down, it escapes along the pipe M, and through the valve *b* into the vessel K.

Ch. Though the water stands no higher than *h*, yet it flows through the pipe F to some height.

Fa. The pipe F *i* is fixed into the top of the vessel, and is made air-tight, so that no air can escape out of it after the water is higher than *i*, the edge of the pipe.

Em. Then the whole quantity of air which occupied the space F *b* is compressed into the smaller space *h* F.

Fa. You are right; and therefore the extra pressure on the water in the vessel forces it through the pipe, as you see.

Ch. And the greater the condensation, that is, the more water you force into the vessel K, the higher the stream will mount.

Fa. Certainly: for the forcing-pump differs from the last in this respect: that there is no limit to the altitude to which

water may be thrown, since the air may be condensed to almost any degree.

The water-works at old London-bridge, alluded to in a previous conversation, exhibited a most curious engine, constructed upon the principle of the forcing-pump: the wheel-work was so contrived as to move either way, as the tide changed. By these works 140,000 hogsheads of water were raised every day.

Em. Is there any rule to calculate the height to which an engine will throw water?

Fa. If the condensation of the air be double that of the atmosphere, its pressure will raise water 33 feet: if the condensation be increased threefold, the water will reach 66 feet; and so on, allowing the addition of 33 feet in height for every increase of *one* to the number that expressed the air's condensation.

Ch. Are fire-engines made in this manner?

Fa. They are all constructed on the same principle; but there are two barrels by which the water is alternately driven into the air-vessel. By these means the condensation is much increased: the water rushes out in a continued stream, and with such velocity, that a raging fire is rather dashed out than extinguished by it.

Garden-engines are also constructed on a principle similar to that we have been describing.

This figure is the representation of a method of raising water from wells of considerable depth.

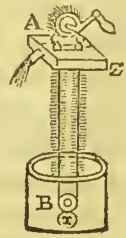

Fig. 86.

Em. Is it a more convenient method than the wheel and axle?

Fa. The wheel and axle are adapted merely to draw up water by buckets: whereas the rope-pump is intended to throw water into a reservoir at almost any height. It consists of three hair ropes passing over the pulleys A and B, which have three grooves in each. The lower pulley, B, is immersed in the water, in which it is kept suspended by a weight, *x*. The pulleys are turned round with great velocity by multiplying wheels, and the cords in their ascent carry up a considerable quantity of water, which they discharge into the box or reservoir *z*, from which, by pipes, it may be conveyed elsewhere. The ropes must not be more than about an inch apart.

Em. What is the reason of that, Papa?

Fa. Because, in that case, a kind of column of water will ascend between the ropes, to which it adheres by the pressure of the atmosphere.

Ch. Ought not this column, in its ascent, to fall back by its own gravity?

Fa. And so it would, did not the great velocity of the ropes occasion a considerable rarefaction of the air near them; consequently the adjacent parts of the atmosphere pressing towards the vacuity, tend to support the water.

Em. Can any considerable quantity of water be raised in this way.

Fa. At Windsor there is a pump of this kind which will raise, by the efforts of one man, about 9 gallons of water in a minute from a well 95 feet deep. In the beginning of the motion, the column of water adhering to the rope is always less than when it has been worked for some time, and the quantity continues to increase till the surrounding air partakes of its motion. There is also another of these pumps at the same place, which raises water from the well in the round tower, 178 feet in depth.

Ch. What is a Chain-pump, Papa?

Fa. A *Chain-pump* is generally used in ships of war, and consists of an endless chain moving over a wheel on the gun-deck, which is turned round by winches, and over a roller in the pump well, having flat circular pistons at certain intervals. Near the pump-well and where the chain ascends there is a pipe, through which the circular pistons raise the column of water, which being lifted over the upper orifice of the pipe, falls into the cistern, and thence into the waste-pipe called the *pump-dale*, which carries it overboard: the descending chain falls through another place called the *back-case.* In large ships these pumps can throw out a ton a minute.

Ch. You told us, some time ago, that when we had seen the nature and understood the construction of valves, you would explain the action of the water-press, called the Hydraulic-press.

Fa. This is a good time for the purpose; and with it I shall conclude our hydrostatical conversations.

You must turn back to fig. 14. *a* is a strong cast-iron cylinder, ground very accurately within, that the piston *e* may

fit exceedingly close and well. I need scarcely tell you that the little figure represents a forcing-pump, with a solid piston, *c*, and a valve, *n*, that opens upwards, through which the water is brought into the pipe *no*. By bringing down the piston *c*, the water in *no* is forced through the valve *x* into the bottom of the cylinder, and thereby drives up the piston *e*.

Ch. What does *m* represent?

Fa. A bundle of hay, or bag of cotton, or any other substance that it may be desirable to bring into a compass twenty or thirty times less than it usually occupies.

Em. I see now the whole operation: the more water there is forced into *eo*, the higher the piston is lifted up, by which the substance *m* is brought into a smaller space.

Fa. Every time the handle *s* is lifted up, the water rushes in from the well or cistern, and when it is brought down, the water must be forced into the cylinder. The power of this engine is only limited by the strength of the materials of which it is made, and by the force applied to it.

Mr. Walker says, a single man, working at *s*, can, by a machine of this kind, bring hay, cotton, &c., into upwards of twenty times less compass than it was before; consequently, a vessel carrying light goods may be made to contain twenty times more packages by means of the hydraulic-press, than it could without its assistance.

QUESTIONS FOR EXAMINATION.

Can you describe the forcing-pump? — In what does the forcing differ from the common sucking-pump? — Upon what principle were the London water-works constructed? — What is the rule to calculate the height to which an engine will throw water? — How are fire-engines constructed? — Can you explain the structure and operations of the rope-pump? — How much water will the rope-pump at Windsor raise in a minute, and from what depth? — Explain the nature of the water-press as it is exhibited in the 14th figure. — What can be done with it?

DEFINITIONS EXPLAINED.

1. *Hydrostatics* is a branch of natural philosophy that treats of the nature, gravity, pressure, and motion of fluids in general.

2. This science is, by some authors, divided into two distinct parts—viz., *Hydrostatics* and *Hydraulics*; the latter relates particularly to the motion of water through pipes, conduits, &c.

3. A fluid is a body the parts of which yield to any impression, and in yielding are easily moved among each other.

4. The air we breathe is a fluid, the parts of which yield to the least pressure.

5. The particles of which fluids are made, are supposed to be exceedingly small, round, and smooth.

6. They are likewise imagined to be very hard, and almost incapable of compression.

7. The particles of water have but a slight attraction for one another.

8. Fluids press in all directions equally.

9. A portion of any kind of fluid gravitates in another when surrounded by a larger portion, in the same way as if it were in the air.

10. A fluid presses in proportion to its perpendicular height, and the base of the vessel containing it, without any regard to the quantity.

11. The specific gravity of any body is its weight compared with any other body ; or more generally,

12. By specific gravities is meant the relative weights of equal bulks of different substances.

13. The lateral or side pressure of fluids is equal to the perpendicular pressure.

14. The hydrostatic paradox is, "That any quantity of water, however small, may be made to balance and support any quantity, however large."

15. The pressure of water and other fluids differs from its gravity or weight in this: that the weight is according to the quantity, but the pressure is according to the perpendicular height.

16. The pressure of fluids against the separate parts of the side of any vessel, taken horizontally, increases as the odd numbers 1, 3, 5, 7, &c.

17. The pressure against the whole side of a vessel must vary as the square of the depth of the vessel.

18. Of three vessels, whose depths are as 1, 2, and 3, the pressure against the side of the second will be four times greater than that against the first, and the pressure against the side of the third will be nine times greater than that against the first.

19. In any cubical vessel, the pressure against any one side is equal to half the pressure upon the bottom: and of course the pressure upon the four sides is equal to twice the pressure upon the bottom.

20. The pressure of any fluid upon the bottom and four sides of a cubical vessel is equal to three times the weight of the fluid.

21. The pressure of the fluid in any conical vessel is found by multiplying the base by the whole perpendicular height; therefore the pressure will be equal to three times its weight.

22. The velocity with which water spouts out at a hole in the side or bottom of a vessel is as the square root of the distance of the hole below the surface.

23. The pressure against the side of a vessel increases in proportion to the square of the depth ; but the velocity of a spouting pipe increases only as the square root of the depth.

24. The horizontal distance to which a fluid will spout from a horizontal pipe in any part of an upright vessel below the surface of the fluid, is equal to twice the length of a perpendicular to the side of the vessel, drawn from the mouth of the pipe to a semicircle described upon the altitude of the vessel.

25. Of several pipes placed horizontally in the side of an upright vessel, that in the centre will spout the furthest: and pipes at equal distances from the centre, above and below, will spout to equal distances.

26. In pipes placed obliquely, that whose elevation is 45° will spout the furthest; and those placed at equal angles above and below 45°, will spout to the same point.

27. Water will not rise so high in a jet, as it does in a tube.

28. Bodies heavier than water will sink in it, and those that are lighter than the fluid will swim.

29. Pure rain water, which is the usual standard for comparing the specific

weights of bodies, is everywhere of the same weight, and a cubic foot weighs exactly a thousand ounces avoirdupoise.

30. The specific gravity of bodies is estimated by the quantities of matter when the bulks are the same.

31. A solid immersed in water sustains a pressure on all sides, which is increased in proportion to the height of the fluid above the solid.

32. A body specifically lighter than water will sink in it till so much of it is below the surface, that a bulk of water equal to the bulk of the parts of the body which is below the surface is of a weight equal to the weight of the whole body.

33. The instrument for comparing the specific gravity of solids is called the Hydrostatic Balance.

34. The rule for obtaining the specific gravity of a body is this: "Weigh the body first in air: then in water, observe what it loses by being weighed in water: and by dividing the former weight by the loss sustained, the result is its specific gravity."

35. Every body, when immersed in water, loses as much of its weight as is equal to the weight of a bulk of water of the same magnitude.

36. If the same body be weighed in different fluids, the specific gravity of the fluids will be as the weights lost.

37. The specific gravity of bodies are to one another inversely as the weights lost by immersion in water.

38. The instrument for comparing the specific gravities of liquids is called the Hydrometer.

39. The Hydrometer is used in breweries and distilleries to ascertain the strength of the liquors, and by the excise officers to gauge the spirits in order to ascertain the duties to be paid to the revenue.

40. All bodies that float on the surface of water displace as much fluid as is equal in weight to the weight of the bodies so floating.

41. Salt-water is specifically heavier than fresh or river water.

42. The specific gravity of the human body is found to be one-ninth less than that of common river water.

43. People in danger of drowning should never raise their arms and hands above the water, and then they cannot sink.

44. Clear water is always one-fourth part deeper than it appears to be.

45. A syphon is a bent tube with unequal legs.—The cause of its action is owing to the pressure of the atmosphere added to the preponderance of weight in the longest leg.

46. The diving-bell is an empty vessel inverted and made sufficiently heavy to sink in water.

47. Pumps for raising water are of two kinds, the sucking and the forcing-pump.

48. The water in a sucking-pump is raised from the well by the pressure the atmosphere; and it can be raised by this means about 34 feet, theoretically, but practically, only 28 feet.

49. A forcing-pump is unlimited, in regard to the height to which it may raise water.

50. An air-vessel is added to a forcing-pump to give an equable stream.

51. A constant stream is produced by means of two barrels, with pistons moving up and down alternately.

52. Plungers are pistons that nearly fill the working barrel: these do not act by the pressure of the atmosphere.

53. Valves are of various kinds: the best are technically described as the clack-valve, the button and tail valve, the conical valve, and the globular valve.

PNEUMATICS.

FIRST CONVERSATION.

OF THE NATURE OF AIR.

FATHER — CHARLES — EMMA.

Father. That branch of natural philosophy which is called Pneumatics treats of the mechanical properties of elastic fluids, and especially of atmospheric air—that is, of the nature, weight, pressure, and elasticity of the air which we breathe, and other fluids, and likewise of the several effects dependent upon these properties: it takes its name from the Greek word *pneuma* (πνευμα) " air, or breath."

Ch. You told us, Papa, a few days ago, that the air, though to us invisible, is a fluid; but it surely differs very much from those fluids which you described when treating of Hydrostatics.

Fa. It does: but bring to your recollection the terms by which we defined a fluid, and you will find some agreement.

Ch. You distinguished a fluid as a body, the parts of which yield to the least pressure.

Fa. The air in which we live and move will answer to this definition. Since we are continually immersed in that element, as fish are in the water, if the parts did not yield to the least force, we should be constantly reminded of its presence by the resistance made to our bodies; whereas persons unaccustomed to think on these subjects are not even aware that they are surrounded with a fluid, the weight and pressure of which, if not counterbalanced by some other power, would instantly crush the human frame.

Em. In a still calm day, when we can scarcely discern a single leaf in motion, it is difficult to conceive the existence

of such a fluid; but when, as Thomson, in his "Summer," forcibly expresses it,

> . . . . down at once,
> Precipitant descends a mingled mass
> Of roaring winds, and flames, and rushing floods,

no doubt can remain as to the existence of some mighty unseen power.

Ch. By this quotation, Emma, you take it for granted that the air and the winds are the same.

Fa. This is really the fact, as we shall prove by and bye.

Ch. But I am not yet quite satisfied that the air is such a body as you have described.

Fa. I do not wish, nor do I intend, to proceed a single step till I have made you perfectly understand this point. You see how easily those gold and silver fish move in the water. Can you explain the reason of it?

Ch. Is it not by the exertion of their fins?

Fa. A fish swims by the help of his fins and tail; and fish in general are nearly of the same specific gravity with water. Take away the water from the vessel, and the fish would still have the use of their fins and tail, at least for a short period.

Em. And they would flounder about at the bottom.

Fa. Now consider the case of birds, how they fly. The swallow, for instance, glides as smoothly along in the air as fish do in the water: but if I were to put a bird, or even a butterfly, under a glass receiver, however large, and draw away the air, they would have no more use of their wings than fish have of their fins when out of water. You shall see the experiment in a day or two:

> . . . . If this support
> Were wanting, all the feather'd tribes must drop
> The useless wing. EUDOSIA.

Em. And would they die in that situation, as fish die when taken from their natural element, the water?

Fa. The cases are precisely similar: some fish, as the carp, the eel, and almost all kinds of shell-fish, will live a considerable time out of water: so some creatures, which depend upon air for existence, will live a long time in an exhausted

receiver. A butterfly for instancc, will fall to the bottom apparently lifeless, but admit the air again into the receiver, and it will revive; while from experiments which have been made on miee, rats, birds, rabbits, &c., it is found that they will live but a very few minutes without air.

Em. Such experiments are very eruel.

Fa. And ought not by any means to be indulged in wantonly. They can be only justified upon the presumption that, in the hands, and under the direetion of able philosophers, they may lead to discoverics of importance to the health and happiness of the human raee.

Ch. Can fish live in water from whieh the air is wholly excluded?

Fa. The air is, in faet, as neeessary to their existenee as it is to ours. Besides their fins, fish possess an air-vessel, which gives them full eommand of their various motions in all depths of water, which their fins, without it, would not be equal to.

Em. What do you mean by an air-vessel?

Fa. It is a small bladder of air, so disposed within them, that, by the assistanee of their museles, they are able to contract or dilate it at pleasure. By its *contraction* they beeome specifieally heavier than the water, and sink; by its *dilatation* they become lighter, and rise to the surface more readily.

Ch. Are these operations effected by the external air?

Fa. Chiefly so: for if you take away the air from the water in which a fish is swimming, it will no longer have the power of eontraeting the air-vessel within, which will then become so expanded as to keep the fish on the surface of the water, to its great inconvenience and pain. Yet by experiment it has been shown that if this air-bladder be removed, a fish may still have the power of raising or lowering itself in the water; and Müller in his work on Physiology, says that this air is not derived from without, but secreted by the inner surface of the sac or bladder; and that the air varies considerably as to its component parts at different times and plaees, and even in the same fish, but there is some difference of opinion as to the precise use of this air-bladder.

Ch. Of what is the air composed, Papa?

Fa. Atmospherie air is composed of two gases—viz., oxy-

gen and nitrogen, in the proportion of 20 or 21 parts of oxygen, to 80 or 79 of nitrogen in every volume of 100 parts; but it is never so absolutely pure as this, being always charged with a variable quantity of carbonic acid, and watery vapour. It has been found that the proportion of carbonic present is greater in summer than in winter, and greater in the night than in the day, and in dull weather than in bright weather. Electrical states of the atmosphere, however, diminish the quantity of carbonic acid. Of these gases, the most important and most active is oxygen, the uses of the nitrogen not being yet accurately known. Without oxygen there would be an end to animal life, and it is the most active principle in supporting combustion, and effecting changes in mineral and other matters.

Ch. Are there different proportions of these gases in different parts of the world?

Fa. No, Charles: the component parts of the air are the same in every region of the globe, and in every altitude; even in infected places, the proportions of these gases are the same, and its noxious qualities at that time are owing to the presence of some deleterious matter intermingling with the air, and of too subtle a character to be distinguished, or chemically discovered. Other properties of the air we shall discuss as we proceed.

QUESTIONS FOR EXAMINATION.

What is meant by Pneumatics? — Will the definition given to a fluid comprehend the air?—Is air necessary to the existence of fish? — What is the air-bladder in fish, and what are its uses?

CONVERSATION II.

OF THE AIR-PUMP.

Emma. You alluded yesterday, Papa, to the taking away of air from certain vessels, called receivers. Will you show us how that is performed?

Fa. I will: and I believe it will be the most convincing method of proving to you that the air is a body such as I have described.

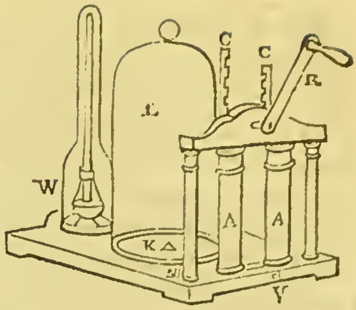

Fig. 1.

This machine is called an air-pump; and its use is to exhaust, or draw off, the air from any vessel, such as this glass receiver L K.

Ch. Does it act like the common pump?

Fa. So much so, that if you comprehend the nature and structure of the one, you will find but little difficulty in understanding the other. I will, however, describe the different parts. A A are two strong brass barrels, within each of which, at the bottom, is fixed a valve, opening upwards: these valves communicate with a concealed pipe that leads to K. The barrels include also moveable pistons, with valves opening upwards. I presume of course that you attended to the structure of the common pump, which was described in Conversation XXI. on Hydrostatics.

Em. How are they moved?

Fa. To the upper parts of the piston are attached racks, a part of which you see at C: these racks are moved up and down in the brass barrels by means of a little cog-wheel, turned round by the handle R.

Ch. You turn the handle but half-way round.

Fa. And by so doing you perceive that one of the racks rises, while the other descends.

Em. What is the use of the screw V.

Fa. It serves to re-admit air into the receiver when it is in a state of exhaustion; for without such a contrivance the receiver could not be moved out of its place after the air was taken from under it. But you shall try for yourselves. I first place a slip of wet leather under the edge of the receiver, because the brass plate is liable to be scratched, and the smallest unevenness between the receiver and plate would prevent the success of our experiment.—I have turned the handle but a few times. Now try to take away the receiver.

Ch. I cannot move it.

Fa. I dare say not: for now the greater part of the air is taken from under the receiver, and consequently it is pressed down with the weight of the atmosphere on the outside.

Em. Pray explain how the air was taken away.

Fa. By turning the winch R half way round, I raise one of the pistons, and thereby leave a vacuum in the lower part of the barrel, when a portion of the air in the receiver rushes through the pipe into the empty barrel. By turning the winch the other way, which raises the other piston, a vacuum would be left in that barrel, did not another portion of air rush from the receiver into it.

Ch. When the first piston descends, does the air in the barrel open the little valve, and escape by the rack C?

Fa. It does: and, by the alternate working of the piston, so much of the air is taken away, that the quantity left has not force enough to raise the valve.

Ch. Cannot you take all the air from the receiver?

Fa. Not by means of the air-pump.

Em. What is the reason that a mist comes on the inside of the glass receiver while the air is exhausting?

Fa. It is explained by the sudden expansion of the air left in the receiver, which we shall notice more particularly in our conversations on Chemistry. The fact is described, as well as the general operation of the air-pump, by Dr. Darwin, in his "Botanic Garden"—

> How, as in brazen pumps the pistons move,
> The membrane valve sustains the weight above;
> Stroke follows stroke, the gelid vapour falls,
> And misty dew-drops dim the crystal walls:
> Rare and more rare expands the fluid thin,
> And silence dwells with vacancy within.

The last line alludes to a fact hereafter to be explained; namely, that where there is no air, there can be no sound.

Ch. You have not told us the use of the smaller receiver, W, with the bottle of quicksilver within it.

Fa. By means of the concealed pipe there is a communication between this and the larger receiver; and the whole is intended to show to what degree the air in the large receiver is exhausted. It is called the small barometer gauge, the meaning of which you will better understand when the structure of the barometer is explained.—I will now show you an experiment or two, by which the resistance of the air is clearly demonstrated.

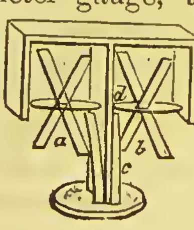

Fig. 2.

Em. Are these little mills for the purpose?

Fa. Yes, they are: the machine consists

of two sets of vanes, *a* and *b*, made equally heavy, and to move on their axes with the same freedom.

Ch. But the vanes of *a* are placed edgeways, and those of *b* are breadthways.

Fa. They are so placed in order to exhibit in a striking manner the resistance of the atmosphere; for, as the little mill *a* turns, it is resisted only in a small degree, and will go round a much longer time than the other, which, in its revolutions, meets the air with its whole surface. By means of the spring *c* resting against the slider *d*, in each mill, the vanes are kept fixed.

Em. Shall I push down the sliders?

Fa. Do so. You see that both set off with equal velocity.

Ch. The mill *b* is evidently declining in swiftness, while the other goes on as quick as ever.

Fa. Not quite so: for in a few minutes you will find them both at rest.

Now we will place them under the receiver of the air-pump, and, by a little contrivance, we shall be able to set the mills at work after the air is exhausted from the receiver; and then, as there is no sensible resistance against them, they will both move round a considerable time longer than they did in the open air; and the instant that one stops, the other will stop also.

Em. This experiment clearly shows the resisting power of the air.

Fa. It shows also that its resistance is in proportion to the surface opposed to it: for the vane which met and divided the air by the edge only, continued to move the longest while they were both exposed to it; but when that was removed, they both stop together; because there is nothing now to retard their motion but the friction on the pivots, which is the same in both cases.—Take this guinea and a feather, and let them both drop from your hand at the same instant.

Ch. The guinea is soon at rest at my feet; but the feather continues floating about. Is the feather specifically lighter than air?

Fa. No: for if it were, it would continue to ascend till it found the air no heavier than itself; whereas, in a minute or two, you will see the feather on the floor as well as the guinea: it is, however, so light, and presents so large a surface to the

air, in comparison with its weight, that it is much longer in falling to the ground than heavier bodies, such as a guinea. Take away the resisting medium, and they will both reach the bottom at once.

Em. How will you do that?

Fa. Upon this brass flap I place the guinea and the feather; and having turned up the flap, and shut it into a small notch, I fix the whole on a tall receiver, with a piece of wet leather between the receiver and the brass. I will now exhaust the air from under the receiver by placing it over the air-pump, and if I turn the wire *f* a little, the flap will slip down, and both the guinea and the feather will fall with equal velocities:

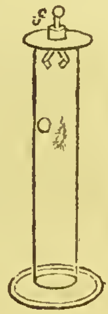

Fig. 3.

> . . . . In perfect void
> All substances with like velocity
> Descend; nor the soft down outstrips the gold.—EUDOSIA.

Ch. They are both at the bottom; but I did not see them fall.

Fa. While I repeat the experiment, you must look steadily at the bottom; because the distance is too small for you to be able to trace their motion: but by keeping your eye at the bottom, you will see the feather and the guinea fall down at the same instant.

In this glass tube is some water; but the air is taken away, and the glass completely closed. Turn it up quickly, so that the water may fall on the other end.

Em. It makes a noise like the stroke of a hammer.

Fa. And for that reason it is usually called the philosophical hammer. The noise is occasioned from want of air to break the fall: for if I take another glass in all respects like it, but having air enclosed in it as well as water, you may turn it as often as you please with scarcely any noise.

Fig. 4.

Suppose you were to put a shrivelled apple into the receiver, you would find, by exhausting the air, the pressure would be taken from it, and it would become as plump as if fresh gathered from the expansion of the air within it: let the air in again, and the apple would become as shrivelled as before. All this proves the elasticity and compressibility of the air.

Ch. Who invented the air-pump, Papa?

Fa. It was invented by Otto Guericke, of Magdeburg, in Germany, about the year 1654; but it has been subsequently much improved by Hooke, Boyle, Smeaton, and others.

QUESTIONS FOR EXAMINATION.

Describe by means of fig. 1, the structure and use of the air-pump. — How is the air taken away from the receiver of the air-pump? — Can the whole of the air be exhausted? — What is the cause of the mist which appears on the inside of the receiver on the exhaustion of the air? — Repeat the lines by Dr. Darwin on this subject. — How will fig. 2 enable you to describe the resistance of the air? — What facts are deducible from this experiment? — Can you describe the experiment of the guinea and feather, and tell me what it is calculated to teach? — What do you mean by the philosophical hammer?

CONVERSATION III.

OF THE TORRICELLIAN EXPERIMENT.

Charles. If by means of the air-pump you cannot perfectly exhaust the air from any vessel, by what means is it done?

Fa. This glass tube is about 36 inches long, and open at one end only. I fill it very accurately with quicksilver, and, placing my thumb over the open end, I invert the tube, and plunge it into a vessel of the same metal, taking care not to remove my thumb till the end of the tube is completely immersed in quicksilver.—You observe the mercury is suspended in the tube to a certain height, and above it there is a perfect vacuum; that is, in the six or seven inches of the upper part of the tube the air is perfectly excluded.

Em. Could not the air get in when you took away your thumb?

Fa. You saw that I did not remove my thumb till the open end of the tube was wholly under the quicksilver; therefore no air could get into the tube without first descending through the quicksilver. You must be aware that a lighter fluid will not descend through one that is heavier; and consequently it is impossible that any air should be in the upper part of the tube.

Ch. What makes the quicksilver stand at that particular height?

Fa. What is the reason that water cannot be raised by means of a common pump higher than about 32 or 33 feet?

Ch. Because the pressure of the atmosphere is equal to the pressure of a column of water so many feet in height.

Fa. And the pressure of a column of quicksilver 29 or 30 inches high, a little more or less, according to the variation of the air, is equal to the pressure of a column of water 32 or 33 feet high, and consequently equal to the pressure of the whole height of the atmosphere.

Em. Is then the mercury in the tube kept suspended by the weight of the air pressing on that in the cup?

Fa. It is.

Em. If you could take away the air from the cup, would the quicksilver descend in the tube?

Fa. If I had a receiver long enough to enclose the cup and tube, and were to place them on the air-pump, you would see the effect that a single turn of the handle would have on the mercury; and after a very few turns, the quicksilver in the tube would be nearly on a level with that in the cup.

I can show you, by means of this syringe, that the suspension of the quicksilver in the tube is owing to nothing but the pressure of the air.

Ch. What is the structure of the syringe?

Fa. If you understand in what manner a common water-squirt acts, you will be at no loss about the syringe, which is made like it.

Ch. By dipping the small end of a squirt in water, and lifting up the handle, a vacuum is made, and then the pressure of the air on the surface of the water forces it into the squirt.

Fa. That is the proper explanation.—This vessel D, containing some quicksilver, and the small tube *gf*, 33 inches long, open at both ends, immersed in it, are placed under a large receiver, A B: the brass plate C, put upon it with a piece of wet leather, admits the small tube to pass through it at *h*. I will now screw the syringe H on the tube *gf*, and by lifting up the handle I, a partial vacuum is made in the tube; consequently the pressure of the air in the receiver upon the mercury in the cup D, forces it up into the little tube as high as *x*, just in the same manner as water follows the piston in a common pump.

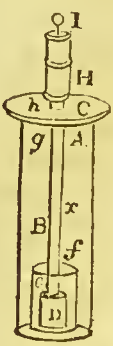

Fig. 5.

Em. But is not this rise of the quicksilver in the tube owing to the suction of the syringe?

Fa. To prove to you that it is not, I place the whole apparatus over the air-pump, and exhaust the air out of the receiver A B. This operation, you must be sensible, has not the smallest effect on the air in the syringe and little tube; but you nevertheless observe that the mercury has again fallen into the cup D: and the syringe might now be worked for ever without raising the mercury in the tube; but admit the air into the receiver, and its action upon the surface of the quicksilver in the cup will force it instantly into the tube.

This is called the Torricellian experiment, or Torricellian vacuum, in honour of Torricelli, a learned Italian, and a disciple of Galileo, who invented it, and who was the first person that discovered the pressure and weight of the air, and introduced the barometer, which we shall by and bye describe.

QUESTIONS FOR EXAMINATION.

How is the air wholly excluded from a vessel, as a glass tube? — What is the pressure of a column of quicksilver about 29 or 30 inches long equal to? — Can you explain the structure and uses of a syringe? — How is it proved that the syringe does not act by means of suction? — Who discovered the weight and pressure of the air?

CONVERSATION IV.

OF THE PRESSURE OF THE AIR.

Charles. It seems very surprising that the air, which is invisible, should produce such effects as you have described.

Fa. If you are not satisfied with the evidence which your eyes are capable of affording, you would perhaps have no objection to the information which your feelings may convey to your mind. Place this little glass, A B, open at both ends, over the hole of the pump-plate, and lay your hand close upon the top B, while I turn the handle of the pump a few times.

Fig. 6.

Ch. It hurts me very much! I cannot take my hand away.

Fa. By letting in the air, I release you. The pain was occasioned by the pressure of the air on the outside

of your hand; that being taken away from under it, which served to counterbalance its weight.


Fig. 7.

This is a larger glass of the same kind: over the large end I tie a piece of wet bladder very tight, place it on the pump, and take the air from under it.

Em. Is it the weight of air that bends the bladder so much?

Fa. Certainly: and by turning the handle a few more times I shall burst it, as you see.

Ch. It has made a report as loud as a gun.

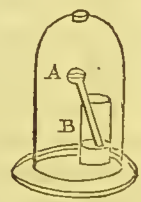

Fig. 8.

Fa. A piece of thin flat glass may be broken in the same manner.—Here is a glass bubble A with a long neck, which I put into a cup of water B, and place them under a receiver on the plate of the air-pump: by turning the handle, the air is not only taken from the receiver, but that in the hollow glass ball will make its way through the water and escape.

Em. Is it the air which occasions the bubbles at the surface of the water?

Fa. It is. And now the bubbling is stopped; and therefore I know that as much of the air is taken away as can be got out by means of the pump. The hollow ball is still empty: but by turning the cock V of the pump (fig. 1) the air rushes into the receiver and presses upon the water; thus filling the ball with the fluid.

Ch. It is not quite full.

Fa. That is because the air could not be perfectly exhausted, and the little bubble of air at the top is what, in its expanded state, filled the whole glass ball, and now by the pressure of the external air is reduced to its present size.

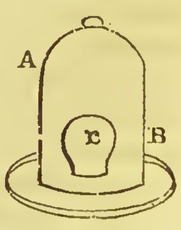

Fig. 9.

Another very simple experiment will convince you that suction has nothing to do with these experiments. On the leather of the air-pump, at a little distance from the hole, I place lightly this small receiver *x*, and pour a spoonful or two of water round the edge of it. I now cover it with a larger receiver, A B, and exhaust the air.

Em. I see by the bubbles round the edge of the small receiver that the air is making its way from under it.

Fa. I have pretty well exhausted all the air. Now can you move the large receiver?

Ch. No: but by shaking the pump, I see the little one is loose.

Fa. The large one is rendered immovable by the pressure of the external air. But the air being taken from the inside of both glasses, there is nothing to fasten down the smaller receiver.

Em. But if suction had anything to do with this, the little receiver would be as firm as the other.

Fa. Turn the cock, v, of the air-pump quickly. Do you not hear the air rushing in with violence?

Ch. Yes, Papa; and the large receiver is loosened again.

Fa. Now take away the smaller one, Emma.

Em. I cannot move it, even with all my strength.

Fa. Nor could you lift it up if you were a hundred times stronger than you are: for, by admitting the air very speedily into the large receiver, it pressed down the smaller one before any air could get underneath it.

Ch. Besides, I imagine you put the water round the edge of the glass to prevent the air from rushing between it and the leather.

Fa. You are right; for air, being the lighter fluid, could not descend through the layer of water in order to ascend into the receiver.—Could suction produce the effect in this experiment?

Ch. I think not; because the little receiver was not fixed till after what might be called suction had ceased to act.

Fa. You are right: and to impress this fact strongly on your mind, I will repeat the experiment. You observe that the air being taken from under both receivers, the large one must be fixed by the pressure of the atmosphere, and the smaller one must be loose; because there is no pressure on its outside, to fasten it. But by admitting the air, the inner one becomes fixed by the very means that the outer one is loosened.

Em. How will you get the small one away?

Fa. As I cannot *raise* it, I must slide it over the hole in the brass plate; and when the air gets under it, there is not the smallest difficulty.

QUESTIONS FOR EXAMINATION

Explain the experiment illustrated by fig. 6.— What effect does the pressure of the air occasion in this instance? — How is the pressure explained by the experiments with fig. 7? — Can you describe the experiment shown by fig. 8? Why is there a bubble left at the top of the glass? — What does the experiment exhibited by fig. 9 prove? — Why can you not move the small glass? — Why could not suction produce the effect?— How will you loosen and get away the small glass that you cannot lift up?

CONVERSATION V.

OF THE PRESSURE OF THE AIR.

Charles. Although suction has nothing in common with the experiments which you made yesterday, yet I think I can show you one instance in which they are connected. This experiment (if such it may be called,) I have made a hundred times. I fasten a string in the centre of a round piece of leather, which I thoroughly soak in water. I then press it with my foot on a flat stone; by which process it is attached so firmly to the stone, that I can it lift up, although the leather be not more than two or three inches in diameter, and the stone weigh several pounds. Surely this is suction.

Fa. I should say so too, if I could not account for it by the pressure of the atmosphere. By treading down the wet leather on the stone, you displace the air from between them; then, by pulling the string, a vacuum is left at the centre, and the pressure of the air about the edges of the leather is so great, that it requires a greater power than the weight of the stone to separate them.

I have seen you drink water from a spring by means of a hollow straw.

Em. Yes, that is another instance of what we have been accustomed to call suction.

Fa. But now you know that in this operation you make a syringe with the straw and your lips, and by drawing in your breath, you cause a vacuum in the hollow straw tube; and the pressure of the air on the water in the spring forces it up, through the straw, into the mouth.

Ch. I cannot, however, help thinking that this looks like

suction; for the moment I cease drawing my breath, the water ceases to rise in my mouth.

Fa. That is, when there is no longer a vacuum in the straw, the pressure within is just equal to that without, and consequently the water will rest at its natural level. Upon a similar principle, we can explain the instinctiveness of the bee, which, to procure the sweet juices that are beyond its reach from deep trumpet-shaped flowers, as the honeysuckle, &c., closes up the orifice with his body, and slowly sucks out the air, consequently the sides collapse, as it were, by the greater external pressure of the air, and the juices are squeezed upward within the reach of the clever little insect. Like the sucker you have adverted to, may be explained the close adhesion of the little limpets to the rocks which you have so often noticed; as well as the apparent difficulty, or rather phenomenon, of flies and other insects walking on glass window panes, on the sides of walls, on ceilings, and on other perpendicular surfaces. Their diminutive feet are supplied by Nature with flat folds of skin which they apply so closely to the surface to be walked on, as to squeeze out the air, and produce a vacuum between their feet and the trodden surface. In consequence of this, the air presses their feet with sufficient force to hold them on the wall, or window glass, or wherever they may alight. If our feet possessed this apparatus, we could walk on the sides of walls and on ceilings with our heads downwards, for the air would press on our feet in the proportion of fifteen pounds to every square inch, which would be equal to a force of more than two hundred-weight, but whether this would be an advantage to us I leave you to guess.

I will show you another striking instance of the effects of atmospheric pressure. This instrument is called the transferrer. The screw C fits on to the plate of the air-pump, and by means of the stop-cocks, G and H, I can take away the air from both, or either of the receivers, I, K, at pleasure.

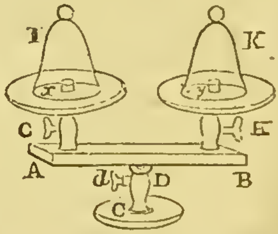

Fig. 10.

Em. Is there a channel, then, running from C through D, A, B, and thence passing to x and y?

Fa. There is. I will screw the whole on the air-pump, and turn the cock G, so that there is now no communication

from C to the internal part of the receiver I. At present you observe that both the receivers are perfectly free. By turning the handle of the pump a few times, the air is taken away from the receiver K, and to prevent its re-entrance, I turn the stop-cock *d*. Try if you can move it.

Ch. I cannot: but the other is loose.

Fa. The pressure of the atmosphere is evidently the same on the two receivers; but with regard to I, the pressure within is equal to that without, and the glass is free: in the other, the pressure from within is taken away, and the glass is fixed. In this stage of the experiment you are satisfied that there is a vacuum in the receiver K. By turning the cock G, I open a communication between the two receivers, and you hear the air that was in I rush through the channel A B into K. Now try to move the glasses.

Em. They are both fixed. How is this?

Fa. The air that was enclosed in the glass I is equally diffused between the two; consequently, the internal pressure of neither is equal to the external, and therefore they are both fixed by the excess of the external pressure over the internal. In this case, it could not be suction that fixed the glass I; for it was free long after what might have been thought suction had ceased to act.

Ch. What are these brass cups?

Fa. They are called the hemispherical cups. I will bring the two, B, A, together, with a wet leather between them, and then screw them by D to the plate of the air-pump: and having exhausted the air from the inside, I turn the stop-cock E, take them from the pump, and screw on the handle F. See if both of you together can separate them.

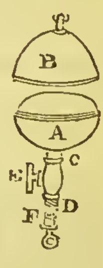

Fig. 11.

Em. We cannot stir them.

Fa. If the diameter of these cups were four inches, the pressure to be overcome would be equal to 180 lbs. I will now hang them up in the receiver, and exhaust the air in it. You see they separate without the application of any force.

Ch. Now there is no pressure on the outside; and therefore the lower cup falls off by its own gravity.

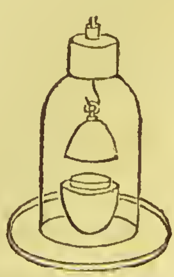

Fig. 12.

Fa. With this steelyard you may try very accurately what weight the pressure of the atmosphere against the cups is equal to.*

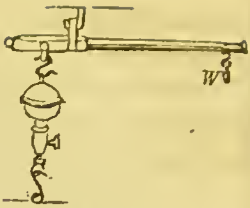

Fig. 13.

Em. For, when the weight, w, is carried far enough to overcome the pressure of the cups, it lifts up the top one.

Fa. I have exhausted the air of this receiver, H; consequently, it is fixed down to the brass plate I: to the plate is joined a small tube with a stop-cock, *x;* by placing the lower end of the tube in a basin of water, and turning the cock, the pressure of the atmosphere on the water in the basin forces it through the tube in the form of a fountain. This is called the fountain *in vacuo.*

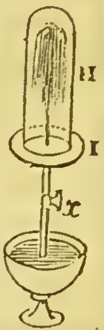

Fig 14.

To this little square bottle, A, (fig. 15) is cemented a screw-valve, by which I can fix it on the plate of the air-pump, and exhaust the air from it: and you will see that when there is no power within to support the pressure of the atmosphere from without, it will be broken into a thousand pieces.

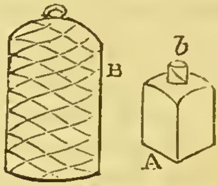

Fig. 15.

Ch. Why did you not use a round phial?

Fa. Because one of that shape would have sustained the pressure like an arch.

Em. Is that the reason why the glass receivers are able to bear so great a weight without breaking?

Fa. It is. If mercury be poured into a wooden cup, C, made of willow, and the air taken from under it, the mercury will, by the weight of the external air, be forced through the pores of the wood, and descend like a shower of rain.

Fig. 16.

The principle of the vacuum is now, in many cases, employed in railroad travelling for propelling carriages from one place to another. A hollow tube of cast-iron, made air-tight, extends the whole distance, and to this is fitted a piston connected at one end by a shank to a carriage above; when the tube, by a powerful steam engine, is exhausted of its air, the piston is released, and by the action

* The principle of the steelyard is explained in Conversation XV. of Mechanics.

of the external air to fill the vacuum, it is forced with great velocity, and with the carriage attached, to its destination.

Its application to locomotive travelling is still in its infancy, and many experiments are still in operation to test its power and efficiency.

QUESTIONS FOR EXAMINATION.

Explain the action of the leather and stone. Is it not by means of suction that children sometimes draw water through a straw from a spring?— Explain the experiment made with the transferrer. Do the same with the brass hemispheres. What is fig. 15 meant to show? — How is mercury made to pass through a piece of wood?

CONVERSATION VI.

OF THE WEIGHT OF AIR.

Emma. We have seen the surprising effects of atmospheric pressure. Are there any means of obtaining the exact weight of the air?

Fa. If you do not require any very great nicety, the method is very simple.

This Florence flask is fitted up with a screw, and a fine oiled-silk, or India-rubber valve at D. I will now screw the flask on the plate of the air-pump, and exhaust the air. You see that, in its present exhausted state, it weighs 3 ounces and 5 grains.

Fig. 17.

Ch. Cannot the air get through the silk?

Fa. The silk, being varnished with a kind of oily substance, is impervious to air; and when the flask is exhausted by the air-pump, the pressure upon the outside effectually prevents the entrance of the air at the edges of the silk: but if I lift it up a little by means of this needle, you will distinctly hear the air rush in.

Em. Is that hissing noise occasioned by the re-entrance of the air?

Fa. It is: and when that ceases, you may be sure the air within the bottle is of the same density as that without.

Ch. Therefore, if I weigh it again, the difference between the weight now and when you tried it before is the weight of the quantity of air contained in the bottle. It weighs very accurately 3 ounces $19\frac{1}{4}$ grains; consequently the air weighs $14\frac{1}{4}$ grains.

Fa. And the flask holds a quart, wine measure.

Em. Does a quart of air always weigh $14\frac{1}{4}$ grains?

Fa. The weight of the air is perpetually changing: therefore, though a quart of it weighs to-day $14\frac{1}{4}$ grains, the same quantity may, in a few hours, weigh $14\frac{1}{2}$ grains, or perhaps only 14 grains, or more, or less. The air is much heavier this morning than it was at the same time yesterday.

Ch. How do you know that? Did you weigh some yesterday?

Fa. No: but the rising and falling of the quicksilver in the barometer, (an instrument which I shall hereafter very particularly describe,) are sure guides to ascertain the real weight of the air; and it stands full three-tenths of an inch higher now than it did yesterday.

Em. Will you explain how we may judge of the different weights of the air by the barometer?

Fa. This subject may, perhaps, be better discussed when we come to treat explicitly on that instrument: but I will now answer your inquiry, although I should be in some danger of a repetition on a future day.

The mercury in a well-made barometer will always subside till the weight of the column be exactly equivalent to the weight of the external air upon the surface of the mercury in the basin; consequently, the height of the mercury is a sure criterion by which that weight is to be estimated.—Suppose, for example, the barometer stands at $29\frac{1}{2}$ inches, or, as it is usually expressed, at 29·5, and I find a quart of air at that time weighs $14\frac{1}{2}$ grains : we here have a standard by which I may ever after compare the gravity of the atmosphere. If to-morrow I find that the quicksilver has fallen to 29·3, I shall know that the air is not so heavy as it was ; because, in this case, a column of quicksilver, 29·3 inches, balances the whole weight; whereas it before required a column equal to 29·5. If, on the contrary, when I look again, the mercury has risen to 30·6, as it really stands at this hour, I am sure the atmosphere is considerably heavier than it was before, and that a quart of it will weigh much more than $14\frac{1}{2}$ grains.

Ch. You intimated that, in weighing air, the flask could not be depended upon if great nicety were required. What is the reason of that?

Fa. I told you, when explaining the operations of the air-

pump, that it was impossible to obtain by means of that machine a perfect vacuum. The want of accuracy in the flask experiment arises from the small quantity of air that is left in the vessel after the exhaustion is carried as far as it will go: this, however, if the pump be good, will, after 12 turns of the handle, be less than the 4000th part of the whole quantity.

Em. How do you know this?

Fa. You seem unwilling to take anything upon my word: and in subjects of this kind you do right never to rest satisfied without a reason for what is asserted.

Suppose, then, each of the barrels of the air-pump equal in capacity to the flask; that is, each will contain a quart, then it is evident that, by turning the handle of the pump, I exhaust all the air of one barrel, and the air in the flask becomes at the same time equally diffused between the barrel and the flask; that is, the quart is now divided into two equal parts, one of which is in the flask, and the other in the barrel. For the same reason, at the next turn of the handle, the pint in the flask will be reduced to half a pint; and so it will go on decreasing, by taking away, at every turn, one half of the quantity left by the last turn.

Ch. Do you mean, then, that, after the first turn of the handle, the air in the bottle is twice as rare as it was at first; and after the second, third, and fourth turns, it is four times, eight times, and sixteen times as rare as it was when you began?

Fa. That is what I meant. Carry on your multiplication, and you will find that, after the twelfth turn, it is 4096 times rarer than it was at first.

Em. I now understand that, though absolute exactness be not attainable, yet, in weighing this quart of air, the error is only equal to the 4096th part of the whole; which quantity may, in reasoning on the subject, be disregarded.

Fa. I will again exhaust the flask of its air, and, putting the neck of it under water, I will lift up the silk valve, and fill it with water. Now dry the outside very thoroughly, and weigh it.

Ch. It weighs 27 ounces.

Fa. Subtract the weight of the flask, reduce the remainder into grains, and divide by $14\frac{1}{4}$, and you will obtain the specific gravity of water, compared with that of air.

Ch. I have done it; and the water is somewhat more than 800 times heavier than air.

Fa. As, therefore, the specific gravity of water is always put at 1, that of air must be as $\frac{1}{800}$th, at least according to this calculation; but, following the more accurate experiments of Mr. Cavendish and others, whose authority may be safely appealed to, the specific gravity of air is 816 times less than that of water; for 1000 cubic inches at a mean temperature and pressure have been found to weigh about 305 grains. The mean height of the barometer at the level of the sea is about 28·6 inches; and a cubic inch of mercury weighs 3425·92 grains; therefore a column of mercury whose base is a square inch, and height the mean height of the barometer, viz. 28·6 inches, weighs 0·48956 multiplied by 28·6, or 14·6 pounds, which is consequently the pressure of the air on every square inch at the surface of the earth. From this we may judge how great a pressure of the air a man sustains, if he has a surface of 15 square feet over his whole body, which is 2160 square inches; the pressure, therefore, is 31·536 pounds, and had he not a counteracting support in the interior of his body, the consequences would be alarming.

QUESTIONS FOR EXAMINATION.

How is the weight of the air ascertained? — The air in passing through a small orifice into a vacuum makes a hissing noise: when the noise ceases, what does it prove? — How much does a quart of air weigh? — How is the weight of the air estimated? — How does the barometer show the weight of the air? — Upon what does the inaccuracy in the flask experiment depend? — To how great a degree of exactness can a vessel be exhausted of air by means of the air-pump? — How is that ascertained? — By how many turns of the handle of the air-pump will this accuracy be obtained? — What is the specific gravity of air compared with that of water? — Is that always the weight?

CONVERSATION VII.

OF THE ELASTICITY OF AIR.

Father. I have told you that air is an elastic fluid. Now, it is the nature of all elastic bodies to yield to pressure, and to endeavour to regain their former figure as soon as the pressure is taken off. In projecting an arrow from your bow,

you exert your strength to bring the two ends nearer together; but the moment you let go the string, it recovers its former shape. The power by which this is effected is called *elasticity*.

Em. Is it not by this power that India-rubber, after it has been stretched, recovers its usual size and form

Fa. It is: and almost everything that you make use of possesses this property in a greater or smaller degree. Balls, marbles, the cords of musical instruments, are all elastic.

Ch. I understand how all these things are elastic; but I do not see in what manner you can prove the elasticity of the air.*

Fa. Here is a bladder, which we fill with air, and tie up the mouth, to prevent its escaping. If you now press upon it with your hand, its figure will be changed; but the moment the pressure is removed, it recovers its round shape.

Em. And if I throw it on the ground, or against any other obstacle, it rebounds, like balls or marbles.

Fa. You are satisfied also, I presume, that it is the air that is the cause of it, and not the bladder that contains it.

Let us have recourse to the air-pump, to exhibit some of the more striking effects of the elasticity of the air. I will let a part of the air out of the bladder, and tie up the mouth again. The pressure of the external air renders it flaccid, and you may make what impression you please upon it, without its endeavouring to re-assume its former figure.

Em. What proof is there that this is owing to the external pressure of the air?

Fa. Such as will satisfy you both, I am sure. Place it under the receiver of the air-pump, exhaust the air, and see the consequences.

Ch. It begins to swell out;—and now it has become as large as when it was blown out full of air.

Fa. The outward pressure being in part removed, the particles of air, by their elasticity, distend, and fill up the bladder; and if it were much larger, and the exhaustion were carried farther, the same small quantity of air would fill it completely. I will now let the air in again.

Em. This exhibits a very striking proof of the power and pressure of the external air; for the bladder is as flaccid as it was before

* See Conversation XIII. Of Mechanics.

Fa. I put the same bladder into this square box, without any alteration, and lay upon it a moveable lid, upon which I place this weight. By bringing the whole under a receiver, and exhausting the external air, the elasticity of that in the bladder will lift up the lid and weight together.

Ch. If you pump much more, the weight will fall against the side of the glass.

Fa. I do not mean to risk that:—it is sufficient for you to see that a few grains of air, not even half a dozen, will, by their elasticity, raise and sustain a weight of several pounds.

Take this glass bubble (fig. 8): the bore of the tube is too small for the water to run out; but if I place it under the receiver of the air-pump, and take away the external air, the little quantity of air which is at the top of the glass will, by its elastic force, expand itself, and drive out all the water.

Em. This experiment shows that a very small quantity of air is capable of filling a large space, provided the external pressure be taken off.

Fa. I will take off the bladder from this glass. (See Hydrostatics, fig. 18.) The little images all swim at the top; the air contained in them rendering them rather lighter than the water. Tie small leaden weights to their feet: these pull them down to the bottom of the vessel. I now place the glass under the receiver of the air-pump, and, by exhausting the air from the vessel, that which is within the images, by its elasticity expands itself, and forces out more water. You see them now ascending to the top, dragging the weights after them. I will let in the air, and the pressure forces the water into the images again, and they descend.

Here is an apple, as I have before remarked to you, very much shrivelled, which, when placed under the receiver, and the external air withdrawn, will appear as plump as if it were newly gathered from the tree.

Em. Indeed it now looks so inviting, that I am ready to wish it were my own.

Fa. Before, however, you can get it, all its beauty will fade. I will admit the air again.

Ch. It is as shrivelled as ever. Do apples contain air?

Fa. Yes, a great deal; and so, in fact, do almost all bodies that are specifically lighter than water, as well as many that are not so. It was the elastic power of the air within the

apple that forced out all the shrivelled parts when the external pressure was taken away.

Here is a small glass of warm ale, from which I am going to take away the air.

Em. It seems to boil, now you exhaust the air from the receiver.

Fa. The bubbling is caused by the air endeavouring to escape from the liquor. Let the air in again, and then taste the beer.

Ch. It is flat and dead.

Fa. You see of what importance air is to give to all our liquors their pleasant and brisk flavour; the same happens to wine and other fermented fluids.

Em. How is it that the air, when it was re-admitted, did not enter the ale again?

Fa. It could not insinuate itself into the pores of the beer, because it is the lighter body, and therefore will not descend through the heavier. Besides, it does not follow that it is the same sort of air which I admitted into the receiver that was taken from the ale.

Em. Are there more kinds of air than one?

Fa. Yes, very many; as we shall show you in our conversations on Chemistry. That which I took from the beer, and which gives it the brisk and pungent taste, is called *fixed air*, or carbonic acid gas, of which there is, as I have before observed, but a very small quantity pervading the atmosphere.

Ch. I have so often heard of carbonic acid gas, that I should have thought it had been very general in the atmosphere.

Fa. I will tell you that this gas is produced whenever carbon, which in its pure state appears in the shape of the diamond and of charcoal, is burned in oxygen gas. A very familiar instance occurs in the burning of a candle, where the black wick represents the carbon, and which, when in contact with the oxygen of the air, supports combustion, gives light, and generates carbonic acid gas: the portion of the wick not within the reach of the oxygen of the air remains unconsumed, and is obliged to be snuffed off: whereas, if it had been open to the air, as is effected by Palmer's patent candles, no snuffing would have been required, and the whole would have been consumed.

Ch. How is this effected by Palmer's patent candles?

Fa. There is a small wire twisted in the wick, which you have observed to be double, the action of the heat makes each portion bend outward into the air, where it receives in consequence the necessary supply of oxygen to consume it. The presence of carbonic acid produces the effervescing quality observable in certain waters; it is contained in marble, chalk, and all lime-stone; it makes lime water turbid; is evolved also in fermentation, and during the respiration of animals; and also extinguishes flame, and suffocates animals, whence miners give it the name of choke-damp.

But to return to our subject: the elasticity, or spring of air, contained in our flesh, was clearly shown by experiment when I pumped the air from under your hand.

Ch. Was that the cause of its swelling downward?

Fa. It was: and it will account for the pain you felt, which was greater, and of a very different kind from that which you would have experienced by a dead weight being laid on the back of the hand, equal to the pressure of the air.

Cupping is an operation performed on this principle. Some operators will tell you that they draw up the flesh; but if they were to speak correctly, they would say they took away a great portion of the external air by dilatation from that part of the body enclosed under the glass, and then the elastic force o the air within extended and puffed out the flesh in readiness for their lancets.

Em. When I saw you cupped, he did not use an air-pump, but little glasses, to raise the flesh.

Fa. Glasses closed at the top are now generally employed, in which the operator holds the flame of a spirit-lamp: by the heat of this the elasticity of the air in the glass is increased, and a great part of it thereby driven out by dilatation. In this state the glass is put on the part to be cupped; and as the inward air cools, it contracts, and the glass adheres to the flesh by the difference of the pressure of the internal and external air: immediately upon this a number of small lancets are suddenly propelled by a spring into the swollen flesh, and the blood flows from the wounds to the extent required: the instrument containing the lancets is called the *scarificator*, and the term *cupping* is used, because glass cups are employed in the operation. If properly performed, it is by no means painful.

By some persons, however, the syringe is considered as the most effectual method of performing the operation; because by flame the air cannot be rarefied more than one half; whereas by the syringe, a few strokes will nearly exhaust it.

Here is another little square bottle, like that before mentioned (fig. 15), excepting that it is full of air, and the mouth sealed so closely that none of it can escape. I enclose it within the wire cage B, and in this state bring them under the receiver, and exhaust the external air.

Ch. With what a loud report it has burst!

Fa. You can easily conceive now in what manner this invisible fluid endeavours continually, by its elastic force, to dilate itself.

Em. Why did you place the wire cage over the bottle?

Fa. To prevent the pieces of the bottle from breaking the receiver; an accident that would probably have happened without this precaution.

Again, take a new-laid egg, and make a small hole in the little end of it; then, with that end downwards, place it in an ale-glass under the receiver, and exhaust the air; the whole contents of the egg will be forced out into the glass by the elastic spring of the small bubble of air which is always to be found in the large end of a new-laid egg.

QUESTIONS FOR EXAMINATION.

What is the nature of elastic bodies? —How is elasticity defined?—Do many bodies possess this property?—How is the elasticity of the air demonstrated?—What will fig. 8 show in proof of this?—Explain the experiment exhibited by fig. 18. Can a shrivelled apple be made to look plump and fair to the sight, and on what does it depend?—Why does ale that is merely warm put on the appearance of boiling under the exhausted receiver of the air-pump?—What effect is produced on beer and other liquids by taking from them the air?—By admitting the air again, does it produce the same lively taste in the liquids that they had before? and if not, why so?—What air is that combined with beer? —How do you account for the pain felt by exhausting the air from under the hand?—How is *cupping* performed? —How do the glasses that are used in the operation act?—Tell me what fig. 15 is meant to show.—What experiment is shown with a new-laid egg?

CONVERSATION VIII.

OF THE COMPRESSION OF AIR.

Father. I have already alluded to the compressibility of air, which it is proper to describe here, as it is a consequence of its elasticity: for, whatever is elastic, is capable of being forced into a smaller space. In this respect, air differs very materially from other fluids.

Ch. You told us that water was compressible in a very small degree.

Fa. I did so: but the compression which can be effected with the greatest power is so very small, that, without the greatest attention and nicety in conducting the experiments, it would never have been discovered. Air, however, is capable of being compressed into a very small space, compared with what it naturally possesses.

Em. The experiment you made, by plunging an ale-glass into water with its mouth downwards, clearly proved that the air which it contained was capable of being reduced into a smaller space.

Fa. This bended tube A B C is closed at A and open at C. It is, in the common state, full of air. I first pour into it a little quicksilver, just sufficient to cover the bottom *a b*: now the air in each leg is of the same density; and as that contained in A B cannot escape, because the lighter fluid will be always uppermost, when I pour more quicksilver in at C, its weight will condense the air in the leg A B; for the air which filled the whole length of the leg is, by the weight of the quicksilver in C B, pressed into the smaller space A x; which space will be diminished as the weight is increased: so that, by increasing the length of the column of mercury in C B, the air in the other leg will be more and more condensed. Hence we learn that the elastic spring of air is always, and under all circumstances, equal to the force which compresses it.

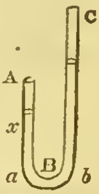

Fig. 18.

Ch. How is that proved?

Fa. If the spring with which the air endeavours to expand itself, when it is compressed, were less than the compressing force, it must yield still farther to that force; that is, if the

spring of the air in A x were less than equal to the weight of the mercury in the other leg, it would be forced into a yet smaller space; but if the spring were greater than the weight pressing upon it, it would not have yielded so much; for you are well aware that action and re-action are equal, and act in opposite directions.

You can now easily understand why the lower regions of the atmosphere are denser than those higher.

Em. Because they are pressed upon by all the air that is above them, and therefore condensed into a smaller space.

Fa. Consequently the air grows gradually thinner, till, at a considerable height, it may be conceived to degenerate to nothing. Suppose the perpendicular height of the atmosphere to be divided into 100 parts, or strata, each an ounce in weight: the lowest part would support the 99 ounces above it, and of course be considerably compressed by the weight; the next part would have to support less, and so on gradually, till it came to the uppermost stratum, which would only have to support its own weight of one ounce: from this we can easily imagine the different degrees of pressure of the atmosphere at the level of the sea and on the tops of lofty mountains, and so in the opposite direction, if a pit were dug to an immense depth, and by way of argument, say to the extent of thirty miles, the density of the air occasioned by the superincumbent pressure would approach to that of water; and at 42 miles it would be of the same density as quicksilver. These different densities of the air, however, may be familiarly illustrated by conceiving twenty or thirty equal packs of wool placed one upon another, the lowest will be forced into a less space; that is, its parts will be brought nearer together, and it will be more dense than the next; and that will be more dense than the third from the bottom, and so on till you come to the uppermost, which sustains no other pressure than that occasioned by the weight of the incumbent air, and would therefore lay loose, and light.

Em. Then I suppose the water at the bottom of the sea must be very dense.

Fa. No; for I have observed to you that water is not an elastic fluid, and therefore not compressible into a smaller volume; so that the water at the top of the ocean is of equal density with that at the bottom.

Let us now see the effects of condensed air, by means of an artificial fountain. This vessel is made of strong copper, and is about half full of water. With a syringe that screws on to the pipe B A, I force a considerable quantity of air into the vessel; so that it is very much condensed. By turning the stop-cock B while I take off the syringe, no water can escape; and, instead of the syringe, I put on a jet, or very small tube; after which the stop-cock is turned, and the pressure of the condensed air forces the water through the tube to a very great height.

Fig. 19.

Ch. Do you know how high it ascends?

Fa. Not exactly: but as the natural pressure of the air will raise water 34 feet, so, if by condensation its pressure be tripled, it will rise 68 feet.

Em. Why tripled? Ought it not to rise to this height by a double pressure?

Fa. You forget that there is the common pressure always acting against, and preventing, the ascent of the water; therefore, besides a force within to balance that without, there must be a double pressure. You must also understand that the density of the air diminishes in the duplicate ratio of its altitude; for if at a certain height from the surface of the earth its density be one half of that which it is at the surface, then at twice the height the density will be only one fourth of that which it is at the surface.

Ch. You described a syringe to be like a common water squirt. How are you able by an instrument of this kind to force in so great a quantity of air? Will it not return by the same way it is forced in?

Fa. The only difference between a condensing syringe and a squirt is, that, in the former there is a valve that opens downwards, by which air may be forced through it; but the instant the downward pressure ceases, the valve, by means of a strong spring, shuts closely, so that none can return.

Em. Will not air escape during the time you are forcing in more of the external air?

Fa. That would be the case if the syringe-pipe went no lower than that part of the vessel which contains the air; but it reaches to a considerable depth in the water; and as it cannot find its way back up the pipe, it must ascend through the

water, and cause that pressure upon it which has been described.

Ch. To what extent can air be compressed?

Fa. If the apparatus be strong enough, and a sufficient power applied, it may be condensed several thousand times; that is, a vessel which will contain a gallon of air in its natural state may be made to contain several thousand gallons.

By means of a fountain of this kind, young people, like yourselves, may receive much entertainment with only a few additional jets, which are made to screw on and off. One kind is so formed that it will throw up and sustain on the stream a little cork ball, scattering the water all around. Another is made in the form of a globe, pierced with a great number of holes, all tending to the centre, exhibiting a very pleasing sphere of water. One is contrived to show, in a neat manner, the composition and resolution of forces explained in Conversation XIII. of Mechanics. Some will form cascades; and by others, when the sun shines at a certain height in the heavens, you may exhibit artificial rainbows.*

We will now force in a fresh supply of air, and try some of these jets.

Em. I observed, in the upright jets, that the height to which the water was thrown was continually diminishing.

Fa. The reason is this: in proportion as the quantity of water in the fountain is lessened, the air has more room to expand, the compression is diminished, and consequently the pressure becomes less, till at length it is no greater within than it is without, and then the fountain ceases altogether

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QUESTIONS FOR EXAMINATION.

In what respect does air differ from other fluids?—Is air easily compressible?—Show me how it is done.—Explain the experiment exhibited by fig. 18.—Why are the lower regions of the atmosphere more dense than those higher up?—How is the density of the air illustrated?—What does the artificial fountain prove?—How is the rise of the water accounted for?—What is the construction of the condensing syringe?—In what respect does it differ from the common squirt?—To what extent can air be compressed?—Are there different kinds of fountains?—Why do the streams coming from artificial fountains continually diminish in height?

* This phenomenon we shall describe and explain when we treat of Optics.

CONVERSATION IX.

MISCELLANEOUS EXPERIMENTS ON THE AIR-PUMP.

Father. To impress what we have been considering more strongly in your memories, I shall, to-day, exhibit a few experiments, without any regard to the particular subjects under which they might be arranged.

In this jar of water I plunge some pieces of iron, zinc, stone, &c.; and you will see that when I exhaust the external air, by bringing the jar under the receiver of the air-pump, the elastic power of the air contained in the pores of these solid substances will force them out in a multitude of globules, and exhibit a very pleasing spectacle, like the pearly dew-drops on the blades of grass; but when I admit the air, they will suddenly disappear.

Em. This proves what you told us a day or two ago, that substances in general contain a great deal of air.

Fa. Instead of bodies of this kind, I will plunge in some vegetable substances, such as a piece or two of the stem of beet-root, angelica, edible rhubarb, &c.; and now observe, when I have exhausted the receiver, what a quantity of air is forced out of the little vessels of these plants by means of its elasticity.

Ch. From this experiment we may conclude that air makes no small part of all vegetable substances.

Fa. To this piece of cork, which of itself would swim on the surface of water, I have tied some lead, just enough to make it sink. By taking off the external pressure, the cork will bring the lead up to the surface.

Em. Is that because, when the pressure is taken off, the substance of the cork expands, and becomes specifically lighter than it was before?

Fa. It is: this experiment may be varied by sinking a bladder in water, in which is tied up a very small quantity of air, for when the external pressure is removed, the elasticity of the air within the bladder will expand it, make it specifically lighter than water, and bring it to the surface.

The next experiment shows that the ascent of smoke and vapours depends on the air. I will blow out this candle, and put it under the receiver; the smoke now rises to the top; but

as soon as the air is exhausted to a certain degree, the smoke descends, like all other heavy bodies.

Ch. Do smoke and vapours rise because they are lighter than the surrounding air?

Fa. Yes: sometimes you see smoke from a chimney rise very perpendicularly in a long column; the air then is very heavy: at other times you may see it descend, which is a proof that the density of the atmosphere is very much diminished, and is, in fact, less than that of the smoke. And at all times the smoke can ascend no higher than where it meets with air of a density equal to itself; and there it will spread about like a cloud.

Em. What is smoke, Papa?

Fa. Properly speaking, smoke is nothing more than the unconsumed and very minute particles of fuel, which are carried up by the warm and rarefied air, which is so much lighter than the atmosphere; but when these are cooled and condensed, they descend again, and often assume the appearance of small black flakes.

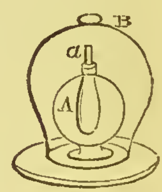


Fig. 20.

This figure is usually called the lungs glass. A bladder is tied close about the little pipe *a*, which is screwed into the bottle A. I introduce it under the receiver A B, and begin to exhaust the air of the receiver, and that in the bladder, communicating with it, will also be withdrawn: the elastic force of the air in the bottle A will now press the bladder into the shrivelled state represented in the figure. I will admit the air, which expands the bladder; and thus by alternately exhausting and re-admitting the air, I show the action of the lungs in breathing. But perhaps the following experiment will give a better idea of the subject. A represents the lungs, B the windpipe leading to them, which is closely fixed in the neck of the bottle from which the air cannot escape: D is a bladder tied to the bottom, and in its distended state (fig. 21) will, with the internal cavity of the bottle, represent that cavity of the body which surrounds the lungs at the moment you have taken in breath: I force up D as in fig. 22, and now the bladder is shrivelled

Fig. 21.

Fig. 22.

by the pressure of the external air in the bottle, and represents the lungs just at the moment of expiration.

Em. Does fig. 21 show the state of the lungs after I have drawn in my breath, and fig. 22 when I have thrown it out forcibly?

Fa. That is what the figures are intended to represent; and they are well adapted to show the elevation and compression of the lungs, although I do not mean to assert that the action of the lungs in breathing depends upon air in the same manner as that in the bladder does upon the air which is contained in the cavity of the bottle.

Ch. For what purpose, Papa, is the air taken into the lungs?

Fa. The object of taking air into the lungs, called respiration, is to aerate the blood, that is, make some interchange of ingredients between that fluid and the air; and without which the functions of the brain would cease, and animal life be destroyed. It has been found that the lungs decompose the air into its elemental principles, or constituent gases, and while retaining the oxygen for the aeration of the blood and support of life, it rejects the nitrogen, and expels also with it a considerable portion of carbonic acid gas and aqueous vapour. From this fact, it may be understood why crowded rooms, where the oxygen has been inspired, and so much carbonic acid expired, and the air, thus deteriorated, and breathed again and again, are so unhealthy and oppressive, often causing intense headache, and considerable languor. It is the oxygen of the air that gives the red colour to the blood.

But to proceed: I have exactly balanced on this scale-beam a piece of lead and a piece of cork: in this state I will introduce them under the receiver, and exhaust the air.

Ch. The cork now seems to be heavier than the lead.

Fa. In air, each body *lost* a weight proportional to its *bulk;* but when the air is taken away, the weight lost will be restored; but as the lead lost least, it will now retrieve the least, consequently the cork will preponderate with the difference of the weights restored by taking away the air.

Thus you see that, in a vacuum, *a pound of cork,* or *feathers,* would be heavier *than a pound of lead.*

QUESTIONS FOR EXAMINATION.

How is it proved that various substances, as metals, stones, &c., contain air? — Show the same of vegetables. — What is inferred from this experiment? — What is the explanation of the experiment with cork? — Can the same be shown by a bladder? — Upon what does the ascent of smoke and vapours depend? — Why does the smoke of a chimney sometimes rise very high and in a perpendicular direction? — What is fig. 20 intended to show? — Explain the same by means of figs. 21 and 22. — What is the experiment of lead and cork intended to prove? — How is this explained? — In what state is a pound of feathers heavier than a pound of lead?

CONVERSATION X.

OF THE AIR-GUN AND SOUND.

Father. The air-gun is an instrument, the effects of which depend on the elasticity and compression of air.

Em. Is it used for the same purposes as common guns?

Fa. Air-guns will answer all the purposes of a musket or fowling-piece: bullets discharged from them will kill animals at the distance of 50 or 60 yards. They make no report; and, on account of the great mischief they are capable of doing, without much chance of discovery, they are often the instrument of the assassin, and are therefore deemed illegal, and are, or ought to be, found nowhere but among the apparatus of the experimental philosopher.

Ch. Can you show us the construction of an air-gun?

Fa. It was formerly a very complex machine, but now its construction is very simple; this is one of the most approved.

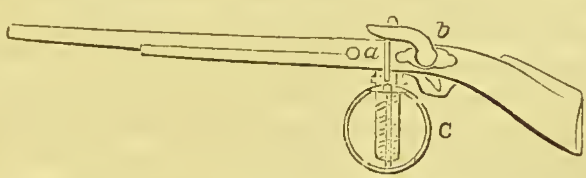


Fig. 23.

Em. In appearance it is very much like a common musket, with the addition of a round ball.

Fa. That ball, c, is hollow, and contains the condensed air, into which it is forced by means of a syringe, and then screwed to the barrel of the gun.

Ch. Is there fixed to the ball c a valve opening inwards?

Fa. There is: and when the leaden bullet is rammed down, the trigger is pulled back, which forces down the hook *b* upon the pin connected with the valve, and liberates a portion of the condensed air; this, rushing through a hole in the lock into the barrel, will impel the bullet to a great distance: the bullet, however, must fit the barrel exactly, so as to admit no windage.

Em. Does not all the air escape at once?

Fa. No: if the gun be well made, the copper ball will contain enough for 15 or 20 separate charges: so that one of these guns is capable of doing much more execution, in a given time, than a common fowling-piece, but it is not so applicable, from requiring some time to charge it.

Ch. Does not the strength of the charges diminish each time?

Fa. Certainly: because the condensation becomes less upon the loss of every portion of air; so that after a few discharges, the ball will be projected only a short distance. To remedy this inconvenience, you might carry a spare ball or two ready filled with condensed air in your pocket, to screw on when the other was exhausted. This kind of instrument is sometimes made as a walking-stick.

Ch. I should like to have one of them

Fa. I dare say you would: but you must not be trusted with instruments capable of doing much mischief, till it is quite certain that your reason will restrain you from actions that might annoy or endanger other persons as well as yourself.

A still more formidable instrument is called the *magazine wind-gun.* In this there is a magazine of bullets as well as another of air, and when it is properly charged, the bullets may be projected one after another as fast as the gun can be cocked and the pan opened. The syringe in these is fixed to the butt of the gun, by which it is easily charged, and may be kept in that state for a great while.

Ch. What is the difference of effect between condensed air and gunpowder in propelling bullets?

Fa. The elastic force of ignited gunpowder may be estimated at from 1000 to 2000 times greater than that of common air; so that air must be condensed upwards of 1000 times to possess the same propulsive power as gunpowder. And since

velocity is as the square root of the force, if the condensation is only ten times, the force acquired is only one hundredth part of that of gunpowder; in the air-gun, however, the propelling force is continued against the bullet throughout the whole length of the barrel, which is not so with gunpowder. for the force ceases to act some time before the bullet quits the barrel.

Em. Does air never lose its elastic power?

Fa. It would be too much to assert that it never will: but experiments have been tried upon different portions of it, which have been found as elastic as ever after the lapse of many months, and even years.

Ch. What is this bell for?

Fa. I took it out to show you that air is the medium by which, in general, sound is communicated. I will place it under the receiver of the air-pump, and exhaust the air. Now observe the clapper of the bell while I shake the apparatus.

Em. I see clearly that the clapper strikes the side of the bell; but I do not hear the least noise.

Fa. Turn the cock and admit the air. Now you hear the sound plainly enough:—and if I use the syringe and a different kind of glass, so as to condense the air, the sound will be very much increased. Dr. Desaguliers says, that in air twice as dense as common air he could hear the sound of a bell at double the distance.

Ch. Is it on account of the different densities of the atmosphere that we hear St. Paul's clock so much plainer at one time than at another?

Fa. Undoubtedly the different degrees of density in the atmosphere will occasion some difference; but the principal cause depends on the quarter from which the wind blows; for as the direction of that is towards or opposite to our house, we hear the clock more or less distinctly.

Em. Does it not require great strength to condense air?

Fa. That depends much on the size of the piston belonging to the syringe: for the force required increases in proportion to the square of the diameter of the piston.

Suppose the area of the base of the piston to be one inch, and you have already forced so much air into the vessel that its density is double that of common air; the resistance opposed

to you will be equal to 15 pounds; but if you would have it ten times as dense, the resistance will be equal to 150 pounds.

Ch. That would be more than I could manage.

Fa. Well, then, you must take a syringe the area of whose piston is only half an inch; and then the resistance would be equal to only the fourth part of 150 pounds, because the square of $\frac{1}{2}$ is equal to $\frac{1}{4}$.*

Em. You said that the air was *generally* the medium by which sound is conveyed to our ears. Is it not always so?

Fa. Air is always a good conductor of sound; so is ice and frozen snow, but water is a still better. Two stones being struck together under water, the sound may be heard at a greater distance, by the ear placed under water in the same river, than it can through the air. In calm weather a whisper may be heard across a wide river.

The slightest scratch of a pin at one end of a long piece of timber may be heard by the ear applied close to the other end, though it could not be heard at half the distance through the air.

The earth is not a bad conductor of sound. It is said, that by applying the ear to the ground, the trampling of horses may be heard much sooner than it could be through the medium of the air. Recourse has sometimes been had to this mode of learning the approach of a hostile army.

Take a long strip of flannel, and in the middle tie a common poker, which answers as well as anything, leaving the ends at liberty: these ends must be rolled round the end of the first finger of each hand, and then, stopping the ears with the ends of these fingers, strike the poker, thus suspended, against any body, such as the edge of a steel fender; the depth of the tone which the stroke will return is amazing: that made by the largest church bell is not to be compared with it.—Thus it appears that flannel is an excellent conductor of sound. But before we proceed I will put a few questions, to ascertain your knowledge of these subjects as far as we have gone.

And first, what conclusions do you deduce from this conversation on the nature of air?

Ch. I understand that the particles of air give way to every small impression, and move freely among one another; so that

* The square of any number being the number multiplied into itself $\frac{1}{2} \times \frac{1}{2} =$

any force that presses upon air, presses in all directions simultaneously.

Fa. Tell me, Emma, what occasions air to be sometimes denser than at other times.

Em. It becomes denser when the pressure upon it is increased.

Fa. And what causes it to expand?

Em. A diminution of pressure, as you proved to us by the experiments we have just witnessed.

Fa. What force is it, Charles, that compresses common air?

Ch. It is the weight of the atmosphere; and the spring of air is equal to that weight; for they always balance each other, and produce equal effects.

Fa. What is the power of the pressure of the atmosphere?

Ch. Near the surface of the earth it is said to be about fifteen pounds avoirdupois upon every square inch.

Fa. What do you remember respecting the elasticity of the air?

Ch. We have been shown, under the head of *repulsion*, that if the particles of a fluid repel each other with a force reciprocally proportional to their distances, such a fluid will be elastic, and capable of compression; and the repulsive force, as well as the attractive, seems to stop at the first particles it acts upon; never extending itself to other particles, which lie beyond the first in a right line.

Fa. What, then, is the nature of the repulsive property of the particles of air?

Ch. There is an opinion that it is produced from certain ponderous substances, and that it is not to be overcome and changed into attraction by any known force whatever. Wherefore, when water is changed into vapour, by having its parts separated and put into a state of repulsion, the vapour is lighter than air; and for this reason they float in it, and are raised up to a considerable height in the atmosphere, where its weight, and consequently its pressure and density, is less than when near the surface of the earth, but equal to the stratum in which it takes its rest.

Fa. Then you conclude that a moist atmosphere is heavier than a clear and dry one?

Ch. Yes; in the proportion that a quantity of suspended

vapours in the first case exceeds the quantity of suspended vapours in the second.

Fa. Do moist vapours lessen the elasticity of the air?

Ch. Yes; because the force of repulsion in them is less than in the particles of air.

Fa. Can you tell me, Emma, why vapours are sometimes visible, and at other times not visible?

Em. When the surrounding air is nearly of the same temperature as the water from which the vapours rise, they are invisible; but when the air is colder than the water, the vapour is condensed as it rises, and becomes visible. Hence it is that the breath of animals is visible only in cold weather.

Fa. What do you imagine the height of our atmosphere to be?

Ch. If the air were a compressed fluid, the height of the atmosphere would be twenty-nine thousand feet, or somewhat above five miles; but as the air is elastic, and expands itself at all altitudes in proportion as the pressure of the incumbent part of the atmosphere decreases, the atmosphere must extend to a much greater height than that above mentioned.

Fa. Can you describe to me the general properties of common air?

Ch. I have understood that it partially consists of a certain *vivifying spirit*, or gas, termed oxygen, which is absolutely necessary to the preservation and continuance of animal life.

Fa. What are the properties, then, of this vivifying gas?

Ch. It is a supporter of combustion, and consequently of a nature proper to feed fire.

Fa. How do you make this evident?

Ch. By several instances; but the most striking is, that if we blow a fire, it burns more fiercely, for the current of air feeds the fire with a continual supply of inflammable particles: and if the fire goes out of itself, it is from not having been effectively fed with fresh air. It is very well known that if we wish to make a fire burn well, it must be supplied with a current of fresh air.

Fa. How is air rendered unhealthy?

Ch. By passing through the fire or through the lungs of any animal, and by corruption and putrefaction, as frequently experienced in the hold of a ship, in mines, wells, and other

close places, which are all charged with that deleterious gas, called carbonic acid gas.

Fa. I am glad to find you both have been so attentive: in our next conversation we will proceed with the nature of sound.

QUESTIONS FOR EXAMINATION.

Upon what do the effects of the air-gun depend? — Will air-guns act like common guns? — What are the characteristics of air-guns? — Explain the construction of an air-gun. — Does all the air of an air-gun escape at a single discharge? — Does the strength of each discharge remain the same? — What is the magazine wind-gun? — Does air never lose its elastic power?—How is it proved that air is the medium of sound? — Why are sounds from a distance heard so much plainer at one time than another? — Is great strength required to condense air? — Upon what does the power required for condensing depend? — How may it be regulated to any given degree? — Is there any other body besides air that will convey sound? — Is the earth a good conductor? — What experiment is shown with a slip of flannel?

CONVERSATION XI.

OF SOUND.

Father. We shall devote this conversation to the consideration of some curious circumstances relating to sound; which, as depending upon the air, will come very properly under Pneumatics; and in doing so we must transfer our ideas from the sensation to the motion that excites that sensation.

Ch. You showed us yesterday that the stroke made by the clapper of a bell was not audible when it was under an exhausted receiver. Is air the cause of sound?

Fa. Certainly, in many cases it is: of this kind is thunder, the most awful sound in nature. In fact, sound is produced by the quick vibration of some body, and it can only reach the ear by means of the air or some other elastic fluid.

Em. Is thunder produced by the air?

Fa. Thunder is generally supposed to be produced by the concussion or striking together of two bodies of air; for lightning, darting through the air, causes, by its great velocity, a vacuum, and the separated bodies of air rushing together produce the noise we call thunder. The same effect, only in miniature, is produced by the ignition of gunpowder.

Ch. Can the report of a large cannon be called a miniature imitation? I remember being once in a room at the distance of but a few paces from the Tower guns when they were fired, and the noise was infinitely worse than any thunder that I ever heard.

Fa. This was because you were near to them: gunpowder, so tremendous as it is in air, when inflamed in a *vacuum* makes no more sound than the bell in like circumstances.

Mr. Cotes mentions a very curious experiment, which was contrived to show that sound cannot penetrate through a vacuum. A strong receiver, filled with common atmospheric air, in which a bell was suspended, was screwed down to a brass plate so tight that no air could escape, and this was included in a much larger receiver. When the air between the two receivers was exhausted, the sound of the bell could not be heard.

Em. Could it be heard before the air was taken away?

Fa. Yes: and also the moment it was re-admitted.

Ch. What is the reason that some bodies sound so much better than others? Bell-metal is more musical than copper or brass; and these sound much better than many other substances

Fa. All sonorous bodies are elastic, the parts of which, by percussion, are made to vibrate, and as long as the vibrations continue corresponding vibrations are communicated to the air; and these produce sound. Musical chords and bells will illustrate this.

Em. The vibrations of the bell are not visible; and musical chords will vibrate after the sound has ceased.

Fa. If light particles of dust be on the outside of a bell when it is struck, you will, by their motion, have no doubt but that the particles of the metal move too, though not sufficiently to be visible to the naked eye: and although the motion of a musical string continues after the sound ceases to be heard, yet it does not follow that sound is not still produced, but only that it is not sufficiently strong to produce a sensation in the ear. You see in a dark night the flash of a gun; but, being at a considerable distance from it, you hear no report.

If, however, you knew that the light was occasioned by the ignition of gunpowder in a musket or pistol, you would con-

clude that it was attended with sound, though it was not sufficiently strong to reach the place where you are.

Ch. Is it known how far sound can be heard?

Fa. We are assured, upon good authority, that the unassisted human voice has been heard at the distance of 10 or 12 miles; namely from New to Old Gibraltar; and in the famous sea-fight between the English and Dutch, in 1672, the sound of cannon was heard at the distance of 200 miles from the place of action. In both these cases the sound passed over water; and it is well known that sound may be always conveyed much further along a smooth than along an uneven surface.

Experiments have been instituted to ascertain in what degree water, as a conductor of sound, was better than land; and a person was heard to read very distinctly at the distance of 140 feet on the Thames: on land he could not be heard further than 76 feet.

Em. Might there not be interruptions in the latter case?

Fa. No noise whatever intervened by land; but on the Thames there was the noise occasioned by the flowing of the water.

Ch. As we were walking last summer, towards Hampstead, we saw a party of soldiers firing at a mark near Chalk-Farm; and you desired us to take notice, as we approached the spot, how much sooner the report was heard after we saw the smoke than when we first got into the fields.

Fa. My intention was that you should know from actual experiment that sound is not conveyed instantaneously, but takes a certain time to travel over a given space.

When you stood close to the place, did you not observe the smoke and hear the report at the same instant?

Em. Yes, we did.

Fa. Then you are satisfied that the light of the flash and the report are always produced together. The former comes to the eye with the velocity of light; the latter reaches the ear with the velocity with which sound travels. If, then, light travels faster than sound, you will, at any considerable distance from a gun that is fired, see the flash before you hear the report. Do you know with what velocity light travels?

Ch. At the rate of 12 millions of miles in a minute.*

* See Conversation XXVI.—Of Astronomy.

Fa. With regard, then, to several hundred yards, or even a few miles, the motion of light may be considered as instantaneous; that is, there would be no assignable difference of time to two observers, one of whom should stand at the breach of the gun, and the other at a distance of six, or eight, or ten miles from it.

Em. This I understand, because 10 miles is as nothing when compared with 12 millions.

Fa. Now, sound travels only at the rate of about 13 miles in a minute; therefore, as time is easily divisible into seconds, the progressive motion of sound is readily marked by means of a stop-watch: consequently if persons are situated, some close to a gun when it is discharged, others at a quarter of a mile from it, and others at half a mile, and so on, they will all see the flash or smoke at the same instant, but the report will reach them at different times.

Ch. Is it certain that sounds of all kinds travel at this rate?

Fa. A great variety of experiments have been made on the subject; and it is now generally agreed that sound travels with a velocity that is equal on the average to 1130 feet in a second of time, at the ordinary temperature of the air.

Em. Then, with a stop-watch, you could have told how far we were from the firing when we first saw it?

Fa. Most easily; for having counted the number of seconds that elapsed between the flash and the report, and then multiplying 1130 by the number, I should find the exact distance in feet between us and the gun.

Ch. Has this knowledge been applied to any practical purpose?

Fa. It has frequently been used at sea, by night, to know the distance of a ship that has fired her watch-guns. Suppose you were in a vessel, and saw the flash of a gun, and between that and the report 24 seconds elapsed, what would be the distance of one vessel from another?

Em. I should multiply 1130 by 24, and then bring the product into miles, which, in this instance, is equal to something more than five miles.

Fa. The mischief occasioned by lightning is supposed to depend much on the distance at which the storm is from the spot from whence it is seen.

By counting the number of seconds elapsed between the flash of lightning and the clap of thunder, you may ascertain how far distant you are from the storm.

Ch. I should like to have a stop-watch, to be able to calculate this for myself.

Fa. As it will, probably, be some time before you become possessed of that expensive article, I will tell you of something which you have always about you, and which will answer the purpose.

Em. What is that, Papa?

Fa. The pulse at your wrist, which, in healthy persons, generally beats about 75 times in a minute. In the same space of time sound flies 13 miles: therefore in one pulsation sound passes over 13 miles, divided by 75, that is about 915 feet, or the $\frac{1}{6}$ part of a mile; consequently in six pulsations it will pass over a mile.

Em. If I see a flash of lightning, and between that and the thunder I count at my wrist 36 or 60 pulsations, I say the distance in one case is equal to six miles; in the other, ten.

Fa. You are right: and this method will, for the present, be sufficiently accurate for all your purposes.

But I will observe, that philosophically speaking, sound is an idea excited in the mind by means of the nerves of the organ of hearing, which, receiving impressions from the external air, communicate corresponding impressions to the brain. In the air itself, sound is propagated or distributed from place to place by certain undulations which originate from the vibrations of the sonorous body.

Ch. You have told us, Papa, that sound travels faster, and is heard more distinctly in proportion to the nature of the surface over which or the medium through which it is conveyed. But what are the chief obstructions to its progress?

Fa. Any object which interferes with the straightforward undulations The earth itself under ground is a great conductor of sound; an instance of which is given in the case of a countryman, who being employed in digging a deep pit, was frightened from his work by dreadful noises, which proved to be nothing more than the trotting of a flock of sheep at a distance of two miles, transmitted to him, probably, by some subterraneous conveyance. There is another instance of sound being conveyed to a great distance. The clock of St.

Paul's was heard to strike by a sentinel lying with his ear to the ground on the terrace at Windsor. But it is conjectured that the conveyance was effected by the water of the Thames, which runs near the castle.

Ch. What number of vibrations are necessary to form a distinct sound?

Fa. About thirty; less than that number would not become audible, and more would become confused. Extreme rapidity, such as a thousand vibrations in a second, would form a kind of whizzing noise. Wind instruments sound by the vibrations of a column of air contained within them, produced by the breath; and in the speaking-trumpet by the voice. As in strings, the shortest are the highest notes, so in a flute, the holes nearest to the mouth in the act of blowing, emit the highest sounds. Whether sound really originates from the string or from the *reaction* of the air displaced by the vibration of the string, has been doubted; but most probably from the latter.

Ch. Does every kind of sound, Papa, whether grave or acute, travel with the same velocity?

Fa. Yes, it does in spring and autumn; but in winter, when cold increases the density of the air, and lessens its elasticity, the velocity is not so great; and in summer, when heat diminishes the density, and increases the elasticity, the velocity is somewhat greater.

The science which treats especially of hearing, and the properties of sound, is called *Acoustics*, which is derived from the Greek word *acouo* (ἀκουω) "I hear." The medical term used for the study of the different sounds of the internal organs of the body, as of the heart and lungs, to ascertain their healthy or diseased state, is called *Auscultation*, from the Latin word *auscultare*, "to listen:" and the instrument employed is called the *Stethoscope*, from the Greek word *stethos* (στηθος), "the chest," and *scopeo* (σκοπεω), "I view or explore."—There is yet another word often used instead of *Acoustics*, as illustrating the doctrine of sounds, which is *Phonics*, from the Greek word *phone* (φωνη), "a sound." And as the science is subject to similar laws to Optics, it is divided, like that science, into three branches; the one illustrating direct sound is called *Phonics;* that illustrating reflected sound is called *Cataphonics*, from the Greek word *cata* (κατα), "from or against;" and the

last, illustrating refracted sound, is termed *Diaphonics,* from the Greek *dia* (δια), "through."

QUESTIONS FOR EXAMINATION.

How is thunder produced? — Does gunpowder, when fired *in vacuo,* produce any sound? — Do you know what was Mr. Cotes's experiment on this subject? — Why do some bodies give out a better sound than others? — What is the cause of sound? — How is it known that the particles of the metal move when a bell is struck? — At what distance has sound been heard? — Can sound be conveyed further along a smooth or a rough surface? — Is water or land the better conductor of sound? — When a gun is fired at a distance, do you hear the sound or see the flash first? — At what rate does light travel? — At what rate does sound travel? — Can this knowledge be applied to any useful purpose? — Upon what does the mischief occasioned by lightning depend? — Can you ascertain at what distance you are from a thunder-storm? — Can this be done by counting the beats of the pulse?

CONVERSATION XII.

OF THE SPEAKING-TRUMPET.

Charles. I have been thinking about the nature of sound, but I do not yet thoroughly comprehend it. I can imagine particles of light issuing from the sun, or other luminous bodies; but I have no idea of particles of sound.

Fa. Sound is not a body like light; but depends, as I observed in the last conversation, on the concussion or striking together of other bodies which are elastic: these, being put into a tremulous motion, excite an undulation in the surrounding air.

Em. Is it like the wave we see in the pond when it is ruffled by the wind?

Fa. It is more like the undulation produced by throwing a stone into still water.

Ch. I have often observed this: the surface of the water then forms itself into circular waves.

Fa. It is probable that the tremulous motion of the parts of a sonorous body communicate undulations in the air in a similar manner. Two obvious circumstances must strike every observer with regard to the undulations in water. (1.) The waves, the further they proceed from the striking body, become less and less distinct, till, if the water be of a sufficient extent, they become invisible and die away. The same thing

takes place with regard to sound: the further a person is from the sounding body, the less distinctly it is heard, till at length the distance is too great for it to be audible: and (2.) the waves on the water are not propagated instantaneously, but are formed one after another in a given space of time. This, from what we have already shown, appears to be the manner in which sound is propagated.

Em. Is sound the effect which is produced on the ear by the undulations of the air?

Fa. It is: and in proportion as these waves are stronger or weaker, the impression, and consequently the sensation, is greater or less. If sound be impeded in its progress by a body that has a hole in it, the waves pass through the hole, and then diverge on the other side as from a centre. Upon this principle the *speaking-trumpet* is constructed.

Ch. What is that, Papa?

Fa. It is a long tube, used for the purpose of making the voice heard at a considerable distance. The length of the tube is from six to twelve or fifteen feet: it is straight throughout, having at one end an aperture, of large diameter, while the other terminates in a proper shape and size to receive the lips of the speaker.

Em. Are these instruments much in use?

Fa. It is believed that they were more used formerly than now: they are certainly of great antiquity. Alexander the Great made use of such a contrivance 335 B.C., to communicate his orders to the army; by means of which, it is asserted, he could make himself perfectly understood at the distance of 10 or 12 miles: but the modern instrument has been assigned to Kircher, about A.D. 1652; yet more especially to Sir Samuel Moreland in 1671. Stentor is celebrated by Homer as one who could call louder than fifty men.

> Heaven's empress mingles with the mortal crowd
> And shouts in STENTOR's sounding voice aloud:
> Stentor the strong, endued with *brazen lungs*,
> Whose throat surpass'd the force of fifty tongues.
>
> POPE'S HOMER, B. V. l. 976.

And from him the speaking-trumpet has been called the Stentorophonic Tube: the termination *phonic* is from the Greek word *phone* ($\phi\omega\nu\eta$), "sound."

Ch. Perhaps Stentor was employed in the army for the

purpose of communicating the orders of the general; and he probably made use of a trumpet for the purpose, which may explain the meaning of *brazen lungs*, as expressed by the poet.

Fa. This is not an improbable conjecture. Besides speaking-trumpets, there are others contrived for assisting the hearing of deaf persons, called ear-trumpets, which differ but little from the speaking-trumpet; but various forms have been employed lately; particularly the flexible India-rubber tubes, which are furnished at one end with a small conical mouth-piece, and at the other with a similar shaped ear-piece, made of ivory or of silver.

If A and B represent two trumpets, placed in an exact line at the distance of 40 feet or more from one another, the

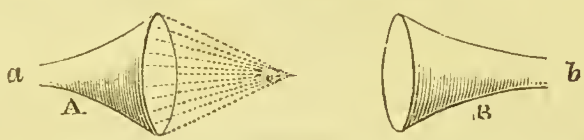


Fig. 24.

smallest whisper at *a* would be heard distinctly at *b*; so that by a contrivance to conceal the trumpets, many of those speaking figures are constructed which are frequently exhibited in the metropolis and other large towns.

Em. I see how it may be done. There must be two sets of trumpets, the one connected with the ear of the image into which the spectator whispers, conveying the sound to a person in another room, who, by tubes connected with the mouth of the image, returns the answer.

Ch. How are the lips set in motion?

Fa. Very easily; by means of a string or wire passing under the floor up the body of the image.

The speaking-trumpet is simply a tube which hinders the spreading of the undulations of the air, and increases the condensation of the air; the condensed air being thrown, by the opposition it meets with from the sides of the instrument, into a course parallel with the axis of the tube; from thence it begins to dilate and spread itself as before, but with greater force; and, in like manner, the force receives a new increase every time the dilatation of the sphere is obstructed by the resistance of the sides of the tube.

Ch. Is there any difference of effect arising from difference in the length of the tube?

Fa. Yes; the increase or power of the sound passing through it is proportional to the length of the tube.

QUESTIONS FOR EXAMINATION.

Upon what does sound depend?—What kind of a wave is made in the air by sound?—What circumstances are observable in the waves made by throwing a pebble into still water?—How do you describe the nature of sound?—Upon what principle does the speaking-trumpet depend?—What is its construction?—Were speaking-trumpets in use among the ancients?—What other name has been given to speaking-trumpets, and why were they so called?—Can you explain, by a reference to fig. 24, how the speaking figures are constructed?

CONVERSATION XIII.

OF THE ECHO.

Father. Let us turn our attention to another curious subject relating to sound, and which also depends on the air. I mean the echo; the term is derived from the Greek word *echo* (ηχω), "a sound."

Em. I have often been delighted to hear my own words repeated; and I once asked Charles how it happened that, if I stood in a particular spot in the garden and shouted loud, my words were distinctly repeated; whereas, if I moved a few yards nearer to the wall, I had no answer? He told me that he knew nothing more of this than what he gathered from a passage in "Ovid's Metamorphoses," where ECHO is represented as having been a nymph of the woods, who had pined away in love, and all that remained of her was her voice.

Ch. I did.

Em. But how could a sound, or the repetition of a sound, be a nymph?

Ch. That is merely a poetical idea, like most of those contained in "Ovid's Metamorphoses."

Fa. This, however, will give your sister but little satisfaction respecting the cause of the echo which she has often heard, and which she may still hear, in the garden.

Em. True, Papa. I cannot conceive why a nymph of the woods should take up her residence in our garden, particularly as I never saw her.

Fa. If she is a mere sound, you cannot see her: I will endeavour to explain the subject. When you throw a stone into a small pool of water, what happens to the waves when they reach the margin?

Ch. They are thrown back again.

Fa. The same happens with regard to the undulations in the air, which are the cause of sound. They strike against any surface adapted to the circumstance, such as the side of a house, a brick wall, a hill, or even against trees, and are reflected or beaten back again. This is the cause of an echo.

Em. I wonder, then, that we do not hear echoes more frequently.

Fa. There must be several concurring circumstances to produce an echo; for the ear must be in the *line of reflection* before it can be heard.

Ch. I do not know what you mean by the line of reflection.

Fa. I cannot always avoid using terms that have not been previously explained; of which this is an instance. I will, however, elucidate what is meant by the line of incidence and the line of reflection. When you come to Optics, the subjects will be made very familiar to you. You can play at marbles?

Ch. Yes; and so can Emma.

Fa. It is not a very common amusement for girls. However, as it happens, I shall find my advantage in it; as she will the more readily enter into my explanation.

Suppose you were to shoot a marble against the wainscot; what would happen?

Ch. That depends on the direction in which I shoot it. If I stand directly opposite to the wainscot, the marble, if I shoot it forcibly enough, will return to my hand.

Fa. The line which the marble describes in going to the wall is called the *line of incidence;* and that which it makes in returning *is the line of reflection.*

Em. They appear to be both the same.

Fa. In this particular instance they are so: but suppose you shoot obliquely or sideways against the board, will the marble return to the hand?

Ch. No; it will fly off sideways in a contrary direction.

Fa. There the line it describes *before the stroke*, or the line of incidence, is different from that of reflection, which it makes *after the stroke.* I will give you another instance: if

you stand before the looking-glass, you see yourself; because the rays of light flow from you, and are reflected back again in the same line. But if Emma stand on one side of the room, and you on the other, you will both see the glass at the upper end of the room.

Em. Yes; and I see Charles in it too.

Ch. I see Emma; but I do not see myself.

Fa. This happens just like the instance of the marble which you shot sideways. The rays flow from Emma obliquely on the glass, upon which they strike, and fly off in a contrary direction; and by them you see her. I will apply this to sound. If a bell, *a*, be struck, and the undulations of the air strike the wall *d* in a perpendicular direction, they will be reflected back in the same line; and if a person were properly situated between *a* and *d*, as at *x*, he would hear the sound of the bell by means of the undulations as they went to the wall, and he would hear it again as they came back; which would be the echo of the first sound.

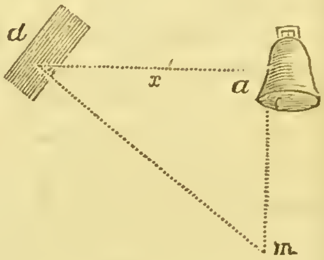


Fig. 25.

Em. I now understand the distinction between the direct sound and the echo.

Fa. If the undulations strike the wall obliquely, they will, like the marble against the wainscot, or the rays of light against glass, fly off again obliquely on the other side, in a reflected line, as *d m*. Now, if there be a hill, or any other obstacle between the bell and the place *m*, where a person happens to be standing, he will not hear the direct sound of the bell, but only the echo of it; and to him the sound will come along the line *dm*.

Ch. I have heard of places where the sound is repeated several times.

Fa. This happens where there are several walls, rocks, &c., which reflect the sound from one to the other, and where a person happens to stand in such a situation as to intercept all the lines of reflection.

There can be no echo unless the direct and reflected sounds follow one another at a sufficient interval of time; for if the latter arrive at the ear before the impression of the direct

sound ceases, the sound will not be doubled, but only rendered more intense.

Em. Is there any rule by which the time may be ascertained?

Fa. Yes, there is. I will begin with the most simple case. If a person stand at *x*, (fig. 25,) the echo cannot be distinct unless the *difference* between the space *a x* and *a d*, added to *dx*, be at least 126 feet.

Ch. The space through which the *direct* sound travels to a person is *a x*, and the whole direct line to the wall is *a d;* besides which, it has to come back through *dx* to reach the person again. All this I comprehend. But why do you say 126 feet in particular?

Fa. It is founded on this principle. By experience it is known that about nine or ten syllables can be articulately and distinctly pronounced in a second of time. But sound travels with the velocity of 1130 feet in a second; therefore, in the ninth part of a second it passes over $\frac{1130}{9}$, or 126 feet nearly, and consequently the reflected sound, which is the echo, must travel over at least 126 feet more than the direct sound, to make it distinct.

Em. If *d* in the figure represent the garden wall, how far must I be from it to hear distinctly any word I utter? Will 63 or 64 feet be sufficient, so that the whole space which the sound has to travel be equal in this case also to 126 feet?

Fa. It must be something more than this; because the first sound rests a certain time on the ear, which should vanish before the echo returns, or it will appear a continuation of the former, and not a distinct sound. It is generally supposed the distance must not be less than 70 or 72 feet: and this will give the distinct echo of one syllable only.

Ch. Must the distance be increased in proportion to the number of syllables that are to be repeated?

Fa. Certainly: and at the distance of about 1000 or 1200 feet, 8 or 10 syllables, properly pronounced, will be distinctly repeated by the echo.

I will finish this subject to-morrow.

QUESTIONS FOR EXAMINATION.

Repeat Ovid's description of an echo.—What is the cause of an echo? — How must the ear be situated to hear an echo? — Explain to me what is meant by the lines of reflection and incidence. — In what case are they both the same? — In what case are they not? — How is this illustrated by means of a looking-glass? — Look to fig. 25, and see if you can explain its meaning.—Explain the distinction between direct sound and echo? — What is the cause of an echo being repeated? — In what case will there be no echo? — What is the least distance at which a person must stand from the reflecting substance to hear an echo? — Must the distance be increased if more syllables than one are to be repeated?

CONVERSATION XIV.

THE ECHO—*continued.*

Father. The following are among the most celebrated echoes. At Rosneath, near Glasgow, there is an echo that repeats a tune played with a bugle, three times, completely and distinctly. Near Rome there was one that repeated what a person said five times. At Brussels there is an echo that answers 15 times. At Thornbury Castle, Gloucestershire, an echo repeats 10 or 11 times very distinctly. In Woodstock Park there is an echo that repeats 17 syllables in the day-time, and one at night. Between Coblentz and Bingen an echo is celebrated as different from most others; as, in common echoes, the repetition is not heard till some time after hearing the words spoken or notes sung; but in this the person who speaks or sings is scarcely heard, but the repetition is very distinct, and in surprising varieties; sometimes seeming to approach, at others to recede: sometimes it is heard distinctly: at others scarcely at all: one person hears only one voice, while another hears several. I shall mention but one more instance. In Italy, at a villa near Milan, the sound of a pistol is returned 56 times.

Em. This is indeed

> "To fetch shrill echoes from their hollow earth."

Fa. The ingenious Mr. Derham applied the echo to measuring inaccessible distances.

Ch. How did he effect this?

Fa. Standing on the banks of the Thames, opposite Woolwich, he observed that the echo of a single sound was re-

flected from the houses in three seconds: consequently, in that time it had travelled 3426 feet; the half of which, or 1713 feet, was the breadth of the river in that particular place.

Did you ever hear of the Whispering-Gallery in the dome of St. Paul's Cathedral?

Em. Yes; and you promised to take us to see it.

Fa. And I will perform my promise. In the mean time it may be well to inform you, that the circumstance which attracts every person's attention is, that the smallest whisper made against the wall on one side of the gallery is distinctly heard on the opposite side.

Ch. Is this effect produced on the principle of the echo?

Fa. No: the undulations caused in the air by the voice are reflected both ways round the wall, which is made very smooth, so that none may be lost, and meet at the opposite side: consequently, to the hearer, the sensation is the same as if his ear were close to the mouth of the speaker.

Em. Would the effect be the same if the two persons were not opposite to each other?

Fa. In that case the words spoken would be heard double, because, one arch of the circle being less than the other, the sound would arrive at the ear sooner round the shorter arch than round the longer one.

Ch. You said that the wall is very smooth. Is it material, in the conveyance of sound, whether the medium be rough or smooth?

Fa. Yes; very material. In Gloucester Cathedral there is also a gallery which conveys a whisper 75 feet across the nave. Still water is, perhaps, the best conductor of sound. The echo I mentioned in the neighbourhood of Milan depends much on the water near which the villa stands. Dr. Hutton, in his Mathematical Dictionary, gives the following instance as a proof that moisture has a considerable effect upon sound. A house in Lambeth-marsh is very damp during winter, when it yields an echo, which abates when it becomes dry in summer. To increase the sound in a theatre at Rome, a canal of water was constructed under the floor, which caused a great difference.

Next to water, stone is considered a good conductor of sound, though the tone is rough and disagreeable. A well-made brick wall has been known to convey a whisper to the

distance of 200 feet nearly. Wood is sonorous, and produces the most agreeable tone: it is therefore the most proper substance for musical instruments; of which we shall say a word or two before we quit the subject of sound.

Em. All wind-instruments, such as flutes, trumpets, &c., must depend on the air: but is it so with stringed instruments?

Fa. They all depend on the vibrations which they make in the surrounding air. I will illustrate what I have to say by means of the Æolian harp, the music of which is produced by the action of the wind; whence the name Æolian, from Æolus, the ancient god of the winds.

If a cord, eight or ten yards long, be stretched very tight between two points, and then struck with a stick, the whole string will not vibrate, but there will be several still places in it, between which the cord will move. Now the air acts upon the strings of the harp in the same manner as the stroke of the stick upon the long cord just mentioned.

Ch. Do not the different notes upon a violin depend upon the different lengths of the strings, which are varied by the fingers of the musician?

Fa. They do: and the current of air acts upon each string, and divides it into parts, as so many imaginary bridges. Hence every string in an Æolian harp, though all are in unison, or harmonious concord, becomes capable of several sounds; from which arises the wild and wonderful harmony of that instrument.

The undulations of the air, caused by the quick vibrations of a string, are well illustrated by a sort of mechanical sympathy that exists among accordant sounds. If two strings on different instruments are tuned in unison, and one be struck, the other will reply, though they be several feet distant from one another.

Em. How is this accounted for?

Fa. The undulations made by the first string being of the same kind as would be made by the second if struck, those undulations give a mechanical stroke to the second string, and produce its sound.

Ch. If all the strings on the Æolian harp are set to the same note, will they all vibrate if only one be struck?

Fa. They will. The fact is well illustrated by bending little bits of paper over each string, and then striking one

sufficiently hard to shake off its paper: you will see that all the others will be shaken also from their strings.

Em. Will not this happen if the strings are not in unison?

Fa. Try it yourself. Alter the notes of all the strings but two, and place the papers on again. Now strike that string which is in unison with another.

Em. The papers on those are shaken off; but the others remain.

Fa. If a string of a violoncello be put in unison with the sound produced by rubbing or striking the edge of a drinking-glass, and both be placed at a distance from each other in the same room, the vibration of the string, when struck, will cause so great a vibration in the glass, that its sound may be distinctly heard; and if the string be struck with great force, the glass will be considerably agitated.

QUESTIONS FOR EXAMINATION.

Can you enumerate some of the principal echoes? — Has the echo ever been applied to any practical purpose? — In what manner have inaccessible distances been measured by the echo? — What is the circumstance that attracts attention in the whispering gallery of St. Paul's? — How is that produced? — How must the persons be placed to hear the whisper in the best manner? — What is the best medium as a conductor of sound? — What instance is adduced by Dr. Hutton? — Next to water, what is the best conductor of sound? — To what distance has a whisper been conveyed by means of a brick wall? — Upon what do musical instruments depend for their sounds? — What circumstance is observable if a long cord stretched out between two points be struck? — Upon what do the notes of a violin depend? — How are the various sounds on an Æolian harp explained? — If one of the strings of an Æolian harp is struck will they all vibrate? — How is this shown? — Is it necessary that the strings should be in unison to produce this effect?

CONVERSATION XV.

OF WINDS.

Father. You know, my children, what the wind is.

Ch. You told us, a few days ago, that you would prove it was only the air in motion.

Fa. I can show you, in miniature, that air in motion will produce effects similar to those produced by a violent wind.

I will place this little mill under the receiver of the air-pump in such a manner that the air, when re-entering, may

catch the vanes. I am exhausting the air. Now observe what happens when the stop-cock is opened.

Em. The vanes turn round with incredible velocity; much swifter than ever I saw the vanes of a real windmill. But what puts the air in motion, so as to cause the wind?

Fa. There are probably many causes united to produce the effect. The principal one seems to be the heat communicated by the sun.

Ch. Does heat produce wind?

Fa. Heat, you know, expands all bodies; consequently it rarefies the air, and makes it lighter. But you have seen that the lighter fluids ascend, and thereby leave a partial vacuum, towards which the surrounding heavier air presses with a greater or less motion, according to the degree of rarefaction, or of heat, which produces it. The air of this room, by means of the fire, is much warmer than that in the passage.

Em. Does the air in the passage incline towards the parlour?

Fa. Take this lighted wax taper, and hold it at the bottom of the door.

Em. I see that the wind blows the flame violently into the room.

Fa. Hold it now at the top of the door.

Ch. There, I perceive, the flame rushes outwards.

Fa. This simple experiment merits your attention. The heat of the room rarefies the air, and, the lighter particles ascending, a partial vacuum is made at the lower part of the room: to supply the deficiency, the dense outward air rushes in, while the lighter particles, as they ascend, produce an outward current at the top of the door. If you hold the taper about midway between the bottom and the top, you will find a part in which the flame is perfectly still, having no tendency either inwards or outwards.

The *smoke-jack*, so common in the chimneys of large kitchens, consists of a set of vanes, something like those of a windmill or ventilator, fixed to wheel-work: these are put in motion by the current of air in the chimney, produced by the heat of the fire; and, of course, the force of the jack depends on the strength of the fire, and *not* upon the quantity of smoke, as the name of the machine would lead you to suppose.

Em. Would you define the wind as a current of air?

Fa. Yes; and properly so; yet the theory of winds is still involved in considerable obscurity; their direction is denominated from the quarter whence they blow.

Ch. When the wind blows from the North or South, do you say it is, in the former case, a North-wind, and in the latter, a South-wind?

Fa. We do. The winds are generally considered to be of three kinds, independently of the names which they take from the points of the compass whence they blow. They are, the *constant*, or those which always blow in the same direction; the *periodical*, or those which blow six months in one direction, and six in a contrary direction; and the *variable*, which appear to be subject to no general rules.

Em. Is there any place where the wind always blows in one direction only?

Fa. Yes; it is common to a very large part of the earth; namely, to all that extensive tract that lies between 30° and 27° South of the equator; it is especially observable in the Atlantic and Pacific oceans.

Ch. What is the cause of this?

Fa. If you examine the globe, you will see that the apparent course of the sun is from East to West, and that it is always vertical to some part of this tract of our globe; and therefore, as the wind follows the sun, it must, of necessity, blow in one direction constantly.

Em. And is that due East?

Fa. It is only so at the equator: for on the North of this line the wind declines a little to the North point of the compass; and this the more so, as the place is situated further towards the North: on the South side the wind will be southerly.

Ch. The greater part of this tract of the globe is water; and I have heard you say that transparent media do *not* receive heat from the sun.

Fa. The greater part is certainly water; but the proportion of land is not small; almost the whole continent of Africa, a great part of Arabia, Persia, the East-Indies, and China, besides the whole, nearly, of New Holland, and numerous islands in the Indian and Pacific oceans: and in the western hemisphere, by far the greatest part of South America, New Spain, and the West-India islands, come within the limits of

30 degrees North and South of the equator. These amazingly large tracts of land absorb the heat, by which the surrounding air is rarefied, and thus the wind becomes *constant*, or blows in one direction.

You will also remember that neither the sea nor the atmosphere are so perfectly transparent as to transmit all the rays of the solar light: many are stopped in their passage; by which both sea and air are warmed to a considerable degree. These constant or general winds are usually called *trade-winds.*

Em. In what part of the globe do the *periodical* winds prevail?

Fa. They prevail in several parts of the eastern and southern oceans, and evidently depend on the sun; for when the apparent motion of that body is North of the equator, (that is, from the end of March to the same period in September,) the wind sets in from the South-west; and the remainder of the year, while the sun is South of the equator, the wind blows from the North-east. These are called the Monsoons, or shifting trade-winds, and are of considerable importance to those who make voyages to the East Indies.

Ch. Do these changes take place suddenly?

Fa. No: some days before and after the change there are calms, variable winds, and frequently the most violent storms. In the Indian ocean the Monsoons blow from October to April from the North-East; but from April to October they constantly blow from the South-west; the latter is accounted for by the great rarefaction of the atmosphere over the vast regions of Eastern Asia during the summer. There are other winds, obtaining names from their immediate localities, as the *Sirocco*, a hot, humid, and relaxing wind, blowing over the South of Italy from the opposite shores of the Mediterranean; the *Simoon* of Arabia, and *Kamsin* of Egypt, both hot, dry, and pestilential winds blowing from the South: there is also the *Harmattan*, an arid wind from the East, blowing over the western coast of Africa.

Again, on the greater part of the coasts situated between the tropics, the wind blows towards the shore in the day-time, and towards the sea at night. These winds are called sea

and land breezes; they are affected by mountains, the course of rivers, tides, &c.

Em. Is it the heat of the sun by day that rarefies the air over the land, and thus causes the wind?

Fa. It is. The following easy experiment will illustrate the subject.

In the middle of a large dish of cold water put a water-plate filled with hot water; the former represents the ocean, the latter the land rarefying the air over it. Hold a lighted candle over the cold water, and blow it out;—the smoke, you see, moves towards the plate. Reverse the experiment by filling the outer vessel with warm, and the plate with cold water; the smoke will move from the plate to the dish.

Ch. In this country there is no regularity in the direction of the winds: sometimes the easterly winds prevail for several days together; at other times I have noticed the wind blowing from all quarters of the compass two or three times in the same day.

Fa. The variableness of the wind in this island depends probably on a variety of causes; for whatever destroys the equilibrium in the atmosphere produces a greater or less current of wind towards the place where the rarefaction exists.

It is generally believed that the electric fluid, which abounds in the air, is the principal cause of the variableness of the wind here. You may often see one tier of clouds moving in a certain direction, and another in a contrary one; that is, the higher clouds will be moving perhaps North or East, while the weather-cock stands directly South or West. In cases of this kind a sudden rarefaction must have taken place in the regions of one set of these clouds, destroying consequently the equilibrium. This phenomenon is frequently found to precede a thunder-storm; from which it has been supposed that the electric fluid is, in this and such like instances, the principal cause in producing the wind: and if, in the more remarkable appearances, we are able to trace the operating cause, we may naturally infer that those which are less so, but of the same nature, depend on a like principle.

Em. Violent storms must be occasioned by sudden and

tremendous concussions in nature. I remember to have seen once, last year, some very large trees torn up by the wind. It is difficult to conceive how so thin and light a body can produce such violent effects.

Fa. The inconceivable rapidity of lightning will account for the suddenness of any storm; and when you are acquainted with what velocity a wind will sometimes move, you will not be surprised at the effects which it is capable of producing.

Ch. Is there any method of ascertaining the velocity of the wind?

Fa. Yes; several machines have been invented for the purpose. But Dr. Derham, by means of the flight of small downy feathers, contrived to measure the velocity of the great storm which happened in the year 1705; and he found that the wind moved 33 feet in half a second; that is, at the rate of 45 miles per hour. It has also been proved that the force of such a wind is equal to the perpendicular force of 10 pounds, avoirdupois weight, on every square foot. Now, if you consider the surface which a large tree, with all its branches and leaves, presents to the wind, you will not be surprised that, in great storms, some of them should be torn up by the roots.

Em. Is the velocity of 45 miles an hour supposed to be the greatest velocity of the wind?

Fa. Dr. Derham thought the greatest velocity to be about 60 miles per hour. But we have tables calculated to show the *force* of the wind at all velocities, from 1 to 100 miles per hour.

Ch. Does the *force* bear any general proportion to the velocity?

Fa. Yes, it does: the force increases in proportion to the *square* of the velocity.

Em. Do you mean, that if, on a piece of board, exposed to a given wind, there is a pressure equal to one pound, and the same board be exposed to another wind of *double* velocity, the pressure will be in this case four times greater than it was before?

Fa. That is the rule. The following short table, selected from a larger one given in vol. ii. of the "*Philosophical Transactions*," will fix the rule and facts in your memory.

Velocity of the wind, in miles, per hour.	Perpendicular force on one square foot in pounds avoirdupois.	Common appellations of the force of these winds.
5	·123	Gentle, pleasant wind.
10	·492	Brisk gale.
20	1·968	Very brisk.
30	4·429	High wind.
40	7·873	Very high wind.
50	12·300	A storm.
60	17·715	A violent storm.
80	31·490	A hurricane.
100	49·200	A violent hurricane.

To mark the foree and veloeity* of the wind, an instrument was invented by Wolfius, like a windmill. Dr. Lind adopted a glass tube in the shape of the letter U, partly filled with water, for the same purpose; and other eontrivanees have been adopted, but they are not of eommon use: the name given to them is that of *Anemometer*, from two Greek words, *anemos* (ἀνεμος) "the wind," and *metron* (μετρον) "a measure."

The *anemoscope* is an instrument indieating the direetion of the wind, formed of a kind of vane or weather-eoek conneeted by wheel work with an index, on whieh is marked the points of the compass: the termination *scope* is from the Greek *scopeo* (σκοπεω) "I behold."

The weather-eoek itself may be ealled an anemoscope.

Ch. Why are the trade-winds called Monsoons?

Fa. It was thought that they were so distinguished in honour of a pilot, named *Monsoon*, who first perceived their advantages, and applied them to navigation; but it seems to be a Malayan word denoting *seasons.*

Em. What are the peeuliarities of those winds whieh are denominated land and sea breezes?

Fa. The sea-breeze eommonly rises in the morning, proceeding slowly in a fine, small, blaek eurl upon the surfaee of the water, and hastening to refresh the shore. At first it is gentle, but gradually inereases till noon; then as gradually

* Mr. Brice discovered, from observations on the clouds, or their shadows moving on the surface of the earth, that the velocity of wind in a storm was nearly 63 miles in an hour, 21 miles in a fresh gale, and nearly 10 miles in a breeze.

declines, and before evening is totally hushed. Soon after this, the land-breezes take their turn, and after a few hours become still. Some have termed these winds *aërial tides.* If they be so, depending on the daily motion of the earth, many causes may perplex so light a fluid as air, and deprive it of the calculation to which water submits. The most reasonable method of accounting for them is on the principles already adduced; namely, the expansion and contraction of the heated atmosphere; but these do not altogether explain the phenomena, as the breezes often vary in time and place.

In these winds, however, we cannot fail, at all events, to trace the wisdom and goodness of the great Creator, who has beneficently sent them for the comfort and wants of His creatures. On most of our coasts the heat would be sometimes almost insupportable in summer without the sea-breeze, whilst the land-breeze corrects the malignity of dews and vapours, and renders wholesome what otherwise would be noxious.

QUESTIONS FOR EXAMINATION.

What is wind? — How are the effects of wind shown by experiment? — What puts the air in motion so as to produce winds? — Show me the experiment with a lighted taper at the door, and explain the reason of the appearances. — Upon what principle does the smoke-jack depend? — How is wind defined? — How is its direction denominated? — How many kinds of wind are there? — Does the wind blow in any part of the earth in one direction only? — What is the reason of this? — Explain this by the globe. — Do transparent media receive heat? — Tell me, then, how the constant winds are to be accounted for. — What other name have they? — Where do the periodical winds prevail? — On what do they depend? — What other names have they? — Why are they called trade-winds? — What experiment will illustrate the subject? — Upon what does the variableness of the wind in an island depend? — Has electricity any effect in producing wind? — Upon what may the suddenness and strength of a storm depend? — By what methods can the velocity of wind be measured? — What is supposed to be the greatest velocity of wind? — By what law does the force of the wind increase?

CONVERSATION XVI.

OF THE STEAM-ENGINE

Father. If you understand the principle of the forcing-pump, you will easily comprehend in what manner the steam-engine acts, the most important of all hydrostatic machines.

Ch. Why do you call it the most important of all machines?

Fa. Steam-engines can be used with advantage in all cases where great power is required. They are adapted to the raising of water from ponds and wells; to the draining of mines, to the various arts and manufactures, to locomotion on railways, to ships, &c., (and, perhaps, without their assistance we should not at this moment have the benefit of coal-fires;) and to many other most useful purposes.

Em. Then there cannot be two opinions entertained respecting their utility. I do not know what we should do without them in winter, or even in summer, since coal is the fuel chiefly used in dressing our food.

Fa. Our ancestors, a century ago, had excavated all the mines of coal as deep as they could be worked without the assistance of this sort of engines: for when the miners have dug a certain depth below the surface of the earth, the water pours in upon them on all sides; consequently they have no means of going on with their work without the assistance of a steam-engine, which is erected by the side of the pit, and, being kept constantly at work, keeps it dry enough for all practical purposes.

The steam-engine was invented during the reign of Charles II., although it was not brought to a degree of perfection sufficient for the draining of mines till nearly half a century after that period.

Ch. To whom is the world indebted for the discovery?

Fa. It is difficult, if not impossible, to ascertain who was the inventor. The Marquis of Worcester described the principle in a small work entitled "A Century of Inventions," which was published in the year 1663, and reprinted some years since in London, as "A way to drive up water by fire."

Em. Did the marquis construct one of these engines?

Fa. No: The invention seems to have been neglected for several years, until Captain Thomas Savery, about 1698, after a variety of experiments, brought it to so great a degree of perfection, as to be enabled to raise water in small quantities to a moderate height.

Ch. Did he take the invention from the Marquis of Worcester's book?

Fa. By some it is stated that he did; but a Dr. Desaguliers, who, in the middle of the last century, entered at large into

the discussion, maintains that Captain Savery was wholly indebted to the marquis, and charges him with having purchased all the books which contained the discovery, and burned them to conceal the piracy. Captain Savery, however, declared that he was led to the discovery by the following accident:—"Having drunk a flask of Florence wine at a tavern, and thrown the flask on the fire, he perceived that the few drops left in it were converted into steam; this induced him to snatch it from the fire, and plunge its neck into a basin of water, which, by the atmospheric pressure, was driven quickly into the bottle."

Em. This was something like an experiment which I have often seen at the tea-table. If I pour half a cup of water into the saucer, and then hold a piece of lighted paper in the cup for a few seconds, and, when the cup is pretty warm, plunge it with the mouth downwards into the saucer, the water almost instantly disappears from it.

Fa. In both cases, the principle is exactly the same: the heat of the burning paper converts the water, that hung about the cup, into steam; but steam, being much lighter than air, expels the air from the cup, which being plunged into the water, the steam is quickly condensed, and a partial vacuum is made in the cup; consequently, the pressure of the atmosphere upon the water in the saucer forces it into the cup, just in the same manner as the water follows the vacuum made in the pump.

Em. Is steam, then, used for the purpose of making a vacuum, instead of a piston?

Fa. Yes: and it is said that Captain Savery was the first person who applied it to the purpose of raising water.

Em. Will you have the kindness, dear Papa, to describe this engine?

Fa. I shall endeavour to give you a general and correct explanation of the principle and mode of acting of one of Mr. Watt's engines, who took out his first patent in 1769, without entering into all its minor parts.

A is a section of the boiler, standing over a fire, about half full of water: B is the steam-pipe which conveys the steam from the boiler to the cylinder C, in which the piston D, made air-tight, works up and down. *a* and *c* are the steam valves, through which the steam enters into the cylinder: it is

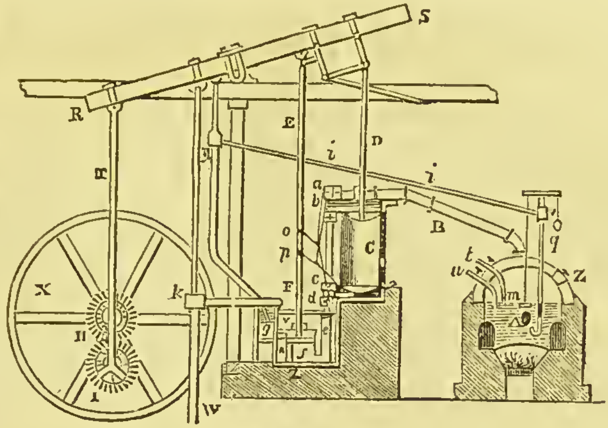


Fig. 26.

admitted through *a* when it is to force the piston downwards, and through *c* when it presses it upwards: *b* and *d* are the eduction valves, through which the steam passes from the cylinder into the condenser *e*, which is a separate vessel placed in a cistern of cold water, and which has a jet of cold water continually playing up in the inside of it: *f* is the air-pump, which extracts the air and water from the condenser. It is worked by the great beam or lever R S, and the water taken from the condenser, and thrown into the hot well *g*, is pumped up again by means of the pump *y*, and carried back into the boiler by the pipe *ii*: *k* is another pump, likewise worked by the engine itself, which supplies the cistern, in which the condenser is fixed, with water.

Ch. Are all three pumps, as well as the piston, worked by the action of the great beam?

Fa. They are: and you see the piston-rod is fastened to the beam by inflexible bars; but in order to make the stroke perpendicular, Mr. Watt invented the machinery called the parallel joint, the construction of which will be easily understood from the figure.

Em. How are the valves opened and shut?

Fa. Long levers, *o* and *p*, are attached to them, which are moved up and down by the piston-rod of the air-pump E F. In order to communicate a rotatory motion to any machinery by the motion of the beam, Mr. Watt made use of a large fly-wheel X, on the axis of which is a small concentric-toothed wheel II; a similar toothed wheel, I, is fastened to a rod, T,

coming from the end of the beam; so that it cannot turn on its axis, but must rise and fall with the motion of the great beam.

A bar of iron connects the centres of the two small-toothed wheels: when, therefore, the beam raises the wheel I, it must move round the circumference of the wheel H, and with it turn the fly-wheel X, which will make two revolutions while the wheel I goes round it once. These are called the sun and planet wheels: H, like the sun, turns only on its axis, while I revolves about it as the planets revolve about the sun.

If to the centre of the fly-wheel any machinery were fixed, the motion of the great beam R S would keep it in constant work.

Ch. Will you describe the operation of the engine?

Fa. Suppose the piston at the top of the cylinder, as it is represented in the figure, and the lower part of the cylinder filled with steam. By means of the pump-rod E F, the steam valve *a* and the eduction valve *d* will be opened together; the branches from which are connected at *o*. There being now a communication at *d* between the cylinder and condenser, the steam is forced from the former into the latter, leaving the lower part of the cylinder empty, while the steam from the boiler, entering by the valve *a*, presses upon the piston, and forces it down. As soon as the piston has arrived at the bottom, the steam valve *c* and the eduction valve *b* are opened, while those at *a* and *d* are shut; the steam, therefore, immediately rushes through the eduction valve *b* into the condenser, while the piston is forced up again by the steam which is now admitted by the valve *c*.

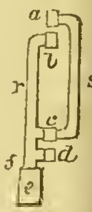


Fig. 27.

QUESTIONS FOR EXAMINATION.

Why is the steam-engine called the most important of all machines? — In what cases is the steam-engine used to advantage? — When was the steam-engine invented? — To whom are we indebted for the discovery? — How is the experiment with the cup explained? — What is used in the steam-engine to make a vacuum? — Try to explain the structure and action of the engine from figures 26 and 27. — Show me the steam-pipe, and tell me its use. — Which are the steam-valves, and what are the uses of them? — Show me the eduction valves and their uses. — What is that represented by *f*, and for what is it used? — How is the air-pump worked? — Is the great beam used for anything else? — Tell me how the valves are opened and shut? — Now describe the action of the engine.

CONVERSATION XVII.

OF THE STEAM-ENGINE — *continued.*

Charles. I do not understand how the two sets of valves act, which you described, yesterday, as the steam and eduction valves.

Fa. If you look to fig. 27 there is a different view of this part of the machine, unconnected with the rest: *s* is part of the pipe which brings the steam from the boiler; *a* represents the valve, which, being opened, admits the steam into the upper part of the cylinder, forcing down the piston.

Em. Is not the valve *d* opened at the same time?

Fa. It is: and then the steam which was under the piston is forced through into the condenser *e.* When the piston arrives at the bottom, the other pair of valves are opened—viz. *c* and *b:* through *c* the steam rushes to raise the piston, and through *b* the steam, which pressed the piston down before, is driven out into the pipe *r*, leading to the condenser: in this there is a jet of cold water constantly playing up; and thereby the steam is instantly converted into hot water.

Ch. Then the condenser *e* (fig. 25) will soon be full of water.

Fa. It would, if it were not connected by the pipe *z* with the pump *f;* so that, every time the great beam R S is brought down, the plunger, at the bottom of the piston-rod E F, descends to the bottom of the pump.

Em. Is there a valve in the plunger?

Fa. Yes: it opens upwards; consequently all the hot water which runs out of the condenser into the pump will escape through the valve, and be at the top of the plunger; and the valve, not admitting any return, it will, by the ascent of the piston-rod into the situation as shown in the figure, be driven through *n* into *g,* the cistern of hot water, from which, by means of a valve, it is prevented from returning.

Ch. I see also that the same motion of the great beam puts the pump *y* in action, and brings over the hot water from the cistern *g,* through the pipe *i i,* into the little cistern V, which supplies the boiler.

Em. If the pump *k* brings in, by the same motion, the water from the well w, do not the hot and cold water intermix?

Fa. No: if you look carefully at the engraving, you will observe a strong partition, *v*, which separates the one from the other. Besides, you may perceive that the hot water does not stand at so high a level as the cold, which is a sufficient proof that they do not communicate. Indeed, the operation of the engine would be greatly injured, if not wholly stopped, if the hot water communicated with the cold; for in that case, the water, being at a medium heat, would be too warm to condense the steam in *e*, and too cold to be admitted into the boiler without checking the production of the steam.

Ch. There are some parts of the apparatus belonging to the boiler which you have not yet explained. What is the reason that the pipe *q*, which conveys the water from the cistern V to the boiler, is turned up at the lower end?

Fa. If it were not bent in that manner, the steam generated at the bottom of the boiler would rise into the pipe, and in a great measure prevent the descent of the water through it.

Em. In this position I see clearly that no steam can enter the pipe; because steam, being much lighter than water, must rise to the surface, and cannot possibly sink through the bent part of the tube. What does *m* represent?

Fa. It represents a stone suspended on a wire, which is shown by the dotted line: this stone is nicely balanced, by means of a lever, at the other end of which is another wire, connected with a valve at the top of the pipe *q*, that goes down from the cistern.

Ch. Is the stone balanced so as to keep the valve open sufficiently to admit a proper quantity of water?

Fa. It is represented by the figure in that situation. By a principle in hydrostatics*, with which you are acquainted, the stone is partly supported by the water. If, then, by increasing the fire, too great an evaporation take place, and the water in the boiler sink below its proper level, the stone also must sink, which will cause the valve to open wider, and let that from the cistern come in faster. If, on the other hand, the evaporation be less than it ought to be, the water will have a tendency to rise in the boiler, and with it the stone must

* See Conversation XI. On Hydrostatics.

rise, and the valve will consequently let the water in with less velocity. By this contrivance the water in the boiler is always kept at one level.

Em. What are the pipes *t* and *u* for?

Fa. They are seldom used; but are intended to show the exact height of the water in the boiler. The one at *t* reaches very nearly to the surface of the water when it is at the proper height: that at *u* enters a little below the surface. If, then, the water be at its proper height, and the cocks *t* and *u* be opened, *steam* will issue from the *former*, and *water* from the *latter*. But if the water be too *high*, it will rush out at *t* instead of steam: if too *low*, steam will issue out of *u* instead of water.

Ch. Suppose the whole to be as represented in the engraving, why will the water rush out of the cock *u*, if it be opened? It will not rise above its level.

Fa. True: but you forget that a constant supply coming into the boiler from the cistern v, makes that the height to which the water will endeavour to rise to attain its level, in the same manner as the jet of cold water always rises to the top of the condenser *e* by endeavouring to come to a level with the water in the cistern. In the next Conversation will be given an account of the purposes to which the steam engine is applied. But perhaps one of the most striking exhibitions of the wonderful effects of this machine is to be seen in that part of the Portsmouth dock-yard where the blocks for ships are made. These blocks are completely finished from the rough timber, with scarcely any manual labour, by means of different saws and other tools worked by the steam-engine.

CONVERSATION XVIII.

OF THE STEAM-ENGINE AND PAPIN'S DIGESTER.

Charles. We have seen the structure of the steam-engine and its mode of operation; but you have not told us the uses to which it is applied.

Fa. The application of this power, especially Mr. Savery's steam-engine, was at first wholly devoted to the raising of water, either from the mines, which could not be worked

without such aid, or to the throwing it to some immense reservoir, for the purpose of supplying with this useful article places which are higher than the natural level of the stream.

Em. But its uses are now wonderfully extended, I suppose.

Fa. They are; such as to the working of mills, threshing of corn, and coining. In making the copper money now in use, the ingenious Mr. Bolton has contrived, by a single operation of the steam-engine, to roll the copper out to a proper thickness, cut it into circular pieces, and make the faces and the edge.

Ch. How is the power of these engines estimated?

Fa. The power varies according to the size. That at Messrs. Whitbread's brewhouse has a cylinder 24 inches in diameter, and will perform the work of 24 horses, working night and day.

Em. The horses, surely, cannot work incessantly.

Fa. They will work only eight hours, on an average, out of the twenty-four, therefore the engine, being continually at work, will perform the business of 72 horses. The coals consumed by this engine are about seven chaldron per week, one chaldron in 24 hours.

By the application of different machinery to this engine, it raises the malt into the upper warehouses, and grinds it; pumps the wort from the under-backs into the copper; raises the wort into the coolers; fills the barrels when the beer is made; and, when the barrels are full, and properly bunged, they are, by the steam-engine, driven into the storehouses in the next street, (a distance of more than a hundred yards,) and let down into the cellar.

Ch. I do not wonder, then, at any anticipated extent of this useful power.

Em. I have heard of *explosive* steam. Pray what is meant by that term?

Fa. From a great variety of accidents that have happened through careless people, it appears that the expansive force of steam, suddenly raised, is much stronger than even that of gunpowder. At the cannon-foundry in Moorfields, some years ago, hot metal was poured into a mould that accidentally contained a small quantity of water, which was instantly converted into steam, and caused an explosion that blew the foundry to pieces. A similar accident happened at a

foundry in Newcastle, which occurred from a little water having insinuated itself into a hollow brass ball that was thrown into the melting-pot.

Ch. These facts bring to my mind a circumstance that I have often heard you relate as coming within your own knowledge.

Fa. You do well to remind me of it. The fact is worth recording. A gentleman, who was carrying on a long series of experiments, wished to ascertain the strength of a copper vessel, and gave orders to his workmen for the purpose. The vessel, however, burst unexpectedly, and in the explosion it beat down a brick wall of the building in which it was placed, and by the force of the steam, was carried 15 or 20 yards from it: several of the bricks were thrown 70 yards from the spot; a leaden pipe, suspended from an adjoining building, was bent into a right angle; and several of the men were so dreadfully scalded, or bruised, that, for many weeks, they were unable to stir from their beds. A very intelligent person, who conducted the experiment, assured me that he had not the smallest recollection how the accident happened, or by what means he got to his bed-room after it.

Ch. What is the use of that immense wheel attached to the large steam-engine in the cloth-factory of Messrs. Edmonds and Co., which we observed when we were at Bradford, in Wiltshire?

Fa. That vast wheel is called the fly-wheel; and in consequence of containing so immense a quantity of matter, when once put in motion it has a tendency to continue the velocity of rotation round its axis, until overcome by friction and the resistance of the air; this inertia enables it to overcome the dead points of power, and to turn the crank of the piston from those extreme positions of its movement where its motive power becomes ineffective, and also to regulate any unequal effect that may attend the crank.

Ch. What is meant by a *non-condensing* steam-engine, Papa?

Fa. Those steam-engines which do not condense the steam after it has performed its office have this appellation; when the steam has impelled the piston, it is not conducted into a cold vessel to condense it into water, but is let off to waste into the atmosphere, and generally into the funnel or

chimney of the furnace. The pressure of the steam, therefore, must be considerably greater than that of the atmosphere, whence these machines have been called *high-pressure* engines; while those which condense their steam are called *low-pressure* engines, though these latter are often worked with steam of a high pressure, amounting sometimes from two to three atmospheres. *Locomotive* engines on railways, and very many of those employed in steam navigation, are high-pressure, non-condensing engines; though generally in steam navigation non-condensing engines with low pressure boilers are adopted.

Ch. How long have locomotive engines been applied to railway travelling? Was not the Liverpool and Manchester railway the first of this kind?

Fa. The first locomotive engine constructed for the transit of goods on railways, was employed in 1804, at Merthyr Tydvil, in South Wales; and from that time till about 1829, they seem to have been almost exclusively applied to the conveying of coals and the mineral products from the mines to the places of their shipment; a short time, however, previous to 1829, it was proposed to form a railway between Liverpool and Manchester for the conveyance of goods and passengers between those two important towns; and to obtain the most efficient means for carrying the design into execution, prizes were offered to the engineers of the country for the best locomotive engines that would answer the end. Accordingly, in October, 1829, when the rails had been laid, experiments were tried, and Mr. Robert Stephenson produced an engine which ran at the rate of 36 miles an hour.

Ch. I think I have heard you mention that Mr. Huskisson, the statesman, was killed on this railway; how was that?

Fa. He was standing on the line talking to a friend, and when apprised of his danger, he became so alarmed as to lose all power of motion, and the engineer being unable to stop the engine within so short a distance, he was knocked down and killed on the spot.

Ch. Were the engines then employed of similar construction with those now used?

Fa. Not exactly; the tubes which conveyed the fire through the boiler were originally of copper, while now they are of brass; there were also but 25 tubes, and about three inches in

diameter, and now there are upwards of 100, whose diameters also are reduced to half the size: moreover the original engines had but four wheels, and now they have six, with many other improvements too extensive to detail at large: the action of these engines is horizontal, acting on the cranks attached to the main axle, which is the middle one: every part is well supplied with oil, to keep them cool and lessen the friction. The supply of water for generating the steam, and of coke for feeding the fire, is carried in the tender attached to the engine: the water, however, is not conveyed in a continual stream, but only at those intervals when the lowest power of the steam is called into requisition, as in descending an incline, for the cold water acts as a check upon its consumption. You must observe, also, that the wheels are not exactly like our coach-wheels, with circular tires, but the two extreme pairs are furnished with sides called flanges, which embrace the rails, and thus keep the wheels more securely on the lines: but it is not necessary to proceed further in our description, as far more profitable information can be derived from actual observation, than double the amount of written description; and when we next have occasion to travel, we will arrive at the station an hour or two earlier, and, by means of some kind friend, we will obtain permission to examine the construction, with the assistance of the engineer.

Em. Is it by the force of steam that bones are dissolved in the cooking utensil, called Papin's digester, which you promised to describe?*

Fa. No; that operation is performed by the great heat produced in the digester. This engraving represents one of these machines. It is a strong metal pot, at least an inch thick in every part: the lid of it is screwed down, so that no steam can escape but through the valve v.

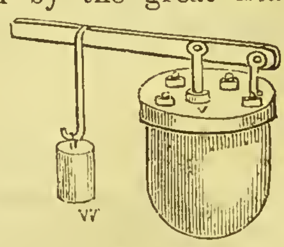


Fig. 28.

Ch. What kind of a valve is it?

Fa. It is a conical piece of brass, made to fit very accurately, but easily moveable by the steam of the water when it boils: consequently, in its simple state, the heat of the water will never be much greater than that of boiling water in an open vessel. A steel-yard is therefore

* See Conversation III.—Of Mechanics.

fitted to it; and, by moving the weight w backwards or forwards, the steam will have a lesser or greater pressure to overcome.

Em. Is the heat increased by confining the steam?

Fa. You have seen that, in an exhausted receiver, water very far from being as hot as the boiling point will have every appearance of ebullition. It is the pressure of the atmosphere that causes the heat of boiling water to be greater in an open vessel than in one from which the air is exhausted. In a vessel exposed to condensed air, the heat required to make the water boil would be still greater. Now, by confining the steam, the pressure may be increased to any given degree. If, for instance, a force equal to 14 or 15 pounds be put on the valve, the pressure upon the water will be double that produced by the atmosphere, and of course the heat of the water will be greatly increased.

Ch. Is there no danger to be apprehended from the bursting of the vessel?

Fa. If great care be taken not to overload the valve, the danger is not very great. But in experiments made to ascertain the strength of any particular vessel, too great precautions cannot be taken.

Under the direction of Mr. Papin, the original inventor, the bottom of a digester was torn off with a wonderful explosion: the blast of the expanded water blew all the coals out of the fire-place; the remainder of the vessel was hurled across the room, and, striking the leaf of an oaken table, an inch thick, broke it in pieces. The least sign of water could not be discerned and every coal was extinguished in a moment.

QUESTIONS FOR EXAMINATION.

To what was the steam-engine first applied? — Has Mr. Bolton applied this machine to any particular purpose? — How is the power of the steam-engine estimated? — To what uses is the steam-engine applied in Whitbread's brewery? — When were locomotive engines first employed on railways? — Distinguish between a high-pressure and low-pressure engine. — Is not steam sometimes productive of very dangerous consequences? — Can you recollect any instances of this kind? — For what is Papin's Digester used? — How is it made? — What kind of a valve is used in the digester? — Can you, by the figure, show how the water is raised to any degree of heat? — What additional pressure is required to give water a heat double that of boiling water?

CONVERSATION XIX

OF THE BAROMETER.

Father. As these conversations are intended to make you familiar with all philosophical instruments in common use, as well as to explain the use and structure of those devoted to the teaching of science, I shall proceed with an account of the barometer, which, with the thermometer, is to be found in almost every house. I will show you how the barometer is made, without regard to the frame to which it is attached.

A B is a glass tube, about 33 or 34 inches long, and a quarter of an inch in diameter, closed at the top; that is, in philosophical language, *hermetically sealed:* D is a cup, basin, or wooden trough, partly filled with quicksilver. I fill the tube with the quicksilver, and then put my finger upon the mouth, so as to prevent any of it from running out: I now invert the tube, and plunge it in the cup D. You see the mercury subsides three or four inches; and when the tube is fixed to a graduated frame, it is called a barometer, or weather-glass; and you know it is consulted by those who study and attend to the changes of the weather: the term barometer is derived from two Greek words, *baros* (βαρος), "weight," and *metron* (μετρον), "a measure."

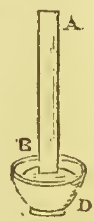


Fig. 29.

Em. Why does not all the quicksilver run out of the tube?

Fa. I will answer you by asking another question. What is the reason that water will stand in an exhausted tube, provided the mouth of it be plunged into a vessel of the same fluid?

Ch. In that case the water is kept in the tube by the pressure of the atmosphere on the surface of the water into which it is plunged. If you resort to the same principle in the present instance, why does the water stand 33 or 34 *feet*, but the mercury only 29 or 30 inches?

Fa. You must recollect that mercury is 14 times heavier than water. Therefore, if the pressure of the atmosphere will balance 34 feet of water, it ought, on the same principle, to balance only a 14th part of that height of mercury. Now divide 34 feet, or 408 inches, by 14.

Em. The quotient is little more than 29 inches.

Fa. By this method Torricelli was led to construct the barometer. It had been accidentally discovered, that water could not be raised more than about 34 feet in the pump. Torricelli, on this, suspected that the pressure of the atmosphere was the cause of the ascent of water in the vacuum made in pumps, and that a column of water, 34 feet high, was an exact counterpoise to a column of air which extended to the top of the atmosphere. Experiments soon confirmed the truth of his conjectures. He then thought that if 34 feet of water were a counterpoise to the pressure of the atmosphere, that a column of mercury, as much shorter than 34 feet as mercury is heavier than water, would likewise sustain the pressure of the atmosphere. He obtained a glass tube for the purpose, and found his reasoning just.

Ch. Did he apply it to the purpose of a weather-glass?

Fa. No, for he died shortly after these experiments; and it was not till some time after this that the pressure of the air was known to vary at different times in the same place. As soon as that was discovered, the application of the Torricellian tube to predicting the changes of the weather immediately succeeded.

Ch. A barometer, then, is an instrument used for measuring the weight or pressure of the atmosphere.

Fa. That is the principal use of the barometer. If the air be *dense*, the mercury rises in the tube, and indicates fair weather: if it grows *light*, the mercury falls, and presages rain, snow, &c.*

The average height of the mercury in the tube is called the *standard altitude*, which in this country fluctuates between 28 and 31 inches; and the difference between the greatest and least altitudes is called the *scale of variation;* the most important matter in making a barometer is to get pure mercury, and a perfect exclusion of all atmospheric air; this is generally effected by boiling the mercury, and even when in the tube; it is also better for the diameter of the tube not to be too small, in order that it may be more susceptible to the changes of the atmosphere.

Em. Is the fluctuation of the mercury different in other parts of the world?

* See the rules at p. 370.

Fa. Within and near the tropics, there is little or no variation in the height of the mercury in the barometer, in all weathers: this is the case at St. Helena. At Jamaica, the variation very rarely exceeds three-tenths of an inch: at Naples it is about an inch: whereas in England it is nearly three inches, and at Petersburgh as much as $3\frac{1}{2}$ inches.

Ch. The scale of variation is the silvered plate, which is divided into inches and tenths of an inch. But what do you call the moveable index?

Fa. It is called a *Vernier*, from the inventor's name; and the use of it is to show the fluctuation of the mercury to the hundredth part of an inch. The scale of inches is placed on the right side of the barometer tube; the beginning of the scale being the surface of the mercury in the basin. The vernier plate and index are moveable; so that the index may, at any time be set to the upper surface of the column of mercury.

Em. I have often seen you move the index; but I am still at a loss to conceive how you divide the inch into hundredth parts by it.

Fa. The barometer-plate is divided into tenths; the length of the vernier is eleven-tenths, but divided into ten equal parts.

Ch. Then each of the ten parts is equal to a tenth of an inch, and a tenth part of a tenth.

Fa. True: but the tenth part of a tenth is equal to a hundredth part; for you remember that to divide a fraction by any number is to multiply the denominator of the fraction by the number; thus, $\frac{1}{10}$ divided by $10 = \frac{1}{100}$.

Suppose the index of the vernier to coincide exactly with one of the divisions of the scale of variation, as 29·3?

Em. Then there is no difficulty. The height of the barometer is said to be 29 inches and 3 tenths.

Fa. Perhaps, in the course of a few hours, you observe that the mercury has risen a very little: what then will you do?

Em. I will raise the vernier even with the mercury.

Fa. And you find the index so much higher than the division 3 on the scale, as to bring the figure 1 on the vernier even with the second tenth on the scale.

Em. Then the whole height is 29 inches, 2 tenths, and one of the divisions on the vernier, which is equal to a tenth and

a hundredth; that is, the height of the mercury is 29 inches, 3 tenths, and 1 hundredth, or 29·31.

Fa. If figure 2 on the vernier stand even with a division on the scale, how should you call the height of the mercury?

Em. Besides the number of tenths, I must add 2 hundredths; because each division of the vernier contains a tenth and a hundredth: therefore, I say, the barometer stands at 29·32; that is, 29 inches, 3 tenths, and 2 hundredths.

Fa. Here is a representation: A is the upper part of a barometer tube: the quicksilver stands at C: from z to x is part of the scale of variation; 1 to 10 is the vernier, equal in length to $\frac{11}{10}$ths of an inch, but divided into 10 equal parts. In the present position of the mercury, the figure 1 on the vernier coincides exactly with 29·5 on the scale; and, finding the index stand between the 6th and 7th divisions on the scale, I therefore read the height 29.61; that is, 29 inches, 6 tenths, and 1 hundredth.

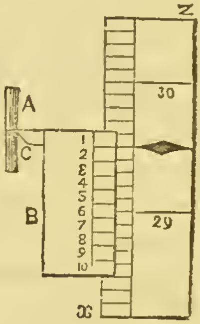


Fig. 30.

Ch. I understand the principle of the barometer; but I want a guide to teach me how to predict the changes of the weather which the rising and falling of the mercury presage.

Fa. I will give you rules for this purpose in a few days.*

Em. What kind of a barometer is that having a large round dial-plate with an index.

Fa. That kind is called a *wheel-barometer*, but they are not considered so correct for philosophical purposes as the simple siphon barometer. In that kind there is a small weight of glass resting on the mercury, and nearly counterpoised by a thread passing over a wheel and supporting another weight: as the mercury falls or rises, so does the weight move which turns the wheel: to this wheel is attached the index hand which meets the eye, and marks the variations of the altitude of the mercury.

* See page 370.

QUESTIONS FOR EXAMINATION.

What is the construction of the barometer? — How is it made? — For what purpose is it used?—What is the reason that water stands in a tube open at one end provided that end be plunged in a vessel of water? — Why does water stand at 33 feet, but the mercury only 29 or 30 inches? — How much heavier is mercury than water? — Who discovered the principle of the barometer? — Did the inventor apply it to discover the changes in the state of the air?— How would you define a barometer?— When does the mercury rise, and when does it fall? — What is meant by the standard altitude? —What is the scale of variation? — How much does the height of the mercury vary in this country? — In what parts of the world is the variation of the mercury the least, and in what is it the greatest? — Of what use is the *vernier?* — Can you explain its application?

CONVERSATION XX.

OF THE BAROMETER, AND ITS APPLICATION TO THE MEASURING OF ALTITUDES.

Charles. Pray, papa, is the height of the atmosphere known?

Fa. If the fluid air were similar to water, which is everywhere of the same density, nothing would be easier than to calculate its height. When the barometer stands at 30 inches, the specific gravity of the atmosphere is 800 times less than that of water;* but mercury is about 14 times heavier than water; consequently the specific gravity of mercury is to that of air as 800 multiplied by 14 is to 1; or mercury is 11,200 times heavier than air. In the case before us, a column of mercury, 30 inches long, balances the whole weight of atmosphere: therefore, if the air were equally dense at all heights to the top, its height must be about 11,200 times 30 inches; that is, the column of air must be as much longer than that of the mercury as the former is lighter than the latter. Do you understand me?

Ch. I think I do: 11,200 multiplied by 30 gives 336,000 inches, which are equal to 5½ miles nearly.

Fa. That would be the height of the atmosphere, if it were equally dense in all parts: but it is found that the air, by its elastic quality, expands and contracts, and that at 3½ miles above the surface of the earth it is twice as rare as it

* See Conversation VI.

is at the surface; at 7 miles it is 4 times rarer; at $10\frac{1}{2}$ miles it is 8 times rarer; at 14 miles it is 16 times rarer; and so on according to the following

TABLE.

At the altitude of	Miles above the surface of the earth the air is		times lighter than at the earth's surface.
$3\frac{1}{2}$		2	
7		4	
$10\frac{1}{2}$		8	
14		16	
$17\frac{1}{2}$		32	
21		64	
$24\frac{1}{2}$		128	
28		256	

Now, if you were disposed to carry on the addition on one side, and the multiplication on the other, you would find that, at 500 miles above the surface of the earth, a single cubical inch of such air as we breathe would be so much rarified as to fill a hollow sphere equal in diameter to the vast orbit of the planet Saturn.

Em. Is it inferred from this that the atmosphere does not reach to any very great height?

Fa. Certainly: for you have seen that a quart of air at the earth's surface weighs but 14 or 15 grains; and by carrying on the above table a few steps, you would perceive that the same quantity, only 49 miles high, would weigh less than the sixteenth-thousandth part of 14 grains; consequently, at that height, its density must be next to nothing. From experiment and calculation it is generally admitted that the atmosphere does not exceed 45 or 50 miles above the earth's surface.

Ch. By comparing the state of the atmosphere at the bottom and at the top of a mountain, could you perceive a sensible difference?

Fa. We must not trust to our feelings on such occasions. The barometer will be a sure guide. I will not trouble you with calculations; but mention two or three facts, with the conclusions to be drawn from them. In ascending the Puy de Dome, a very high mountain in France, the quicksilver fell $3\frac{1}{3}$ inches; and the height of the mountain was found, by measurement, to be 3204 feet. By a similar experiment upon Snowdon, in Wales, the quicksilver was found to have fallen $3\frac{8}{10}$ inches at the height of 3720 feet above the surface of the earth.

From these and many other observations it is inferred that. in ascending any lofty eminence, the mercury in the barometer will fall $\frac{1}{10}$ of an inch for every hundred feet of perpendicular ascent. This number is not rigidly exact, but sufficiently so for common purposes, and it will be easily remembered. The three following observations were taken by Dr. Nettleton, near the town of Halifax:

Perpendicular altitude in feet.	Lowest station of the Barometer.	Highest station of the Barometer.	Difference.
102	29·78	29·66	0·12
236	29·50	29·23	0·27
507	30·00	29·45	0·55

Em. If I ascend a high hill, and, taking a barometer with me, find the mercury has fallen $1\frac{1}{2}$ inch, may I not conclude that the hill is 1,500 feet in perpendicular height?

Fa. You may. Are you aware how great a pressure you are continually sustaining?

Em. No; it never occurred to me. I feel no burden from it; therefore it cannot be very great.

Fa. You sustain, every moment, a weight equal to many tons, which, if it were not balanced by the elastic force of the air within the body, would crush you to pieces. This is well described by Mr. Lofft,

> "*Internal*, balancing *external* force,
> Remove the external, and, to atoms torn,
> Our dissipated limbs would strew the earth:
> Remove the internal, in a moment crush'd
> By greater weight of the incumbent air,
> Than rocks by fabled giants ever thrown."
>
> EUDOSIA.

Ch. We might, indeed, have inferred that it was considerable, from the sensation we felt when the air was taken from under our hands. But how, Papa, do you make out the assertion?

Fa. When the barometer stands at 28·6, which is the mean pressure of the air upon every square inch, it is more than equal to 14 pounds. Call it 14 pounds for the sake of even numbers, and the surface of a middle-sized man is $14\frac{1}{2}$ feet. Tell me now the weight he sustains.

Ch. I must multiply 14 by the number of square inches in $14\frac{1}{2}$ feet. Now, there are 144 inches in a square foot,

consequently, in 143 feet, there are 2,088 square inches: therefore, 14 pounds multiplied by 2,088 will give 29,232, the number of pounds weight which such a person has to sustain.

Fa. That is equal to about 13 tons. Now, if Emma reckon herself only half the size of a grown person, she will sustain $6\frac{1}{2}$ tons.

Em. What must the whole earth sustain?

Fa. This you may calculate at your leisure. I will furnish you with the rule.

"Find the diameter of the earth,* from which you can easily get the superficial measure in square inches; and this you must multiply by 14, and you get the answer to the question in pounds avoirdupois."

The earth's surface contains about 200,000,000 square miles; and as every square mile contains 27,876,400 square feet, there must be 5,575,080,000,000,000 square feet in the earth's surface; which number, multiplied by the pressure on each square foot, gives the whole weight of the atmosphere.

I will now give you some rules for judging of the state of the weather, which are taken from writers who have paid the most attention to these subjects, and which my own observations have in a great degree verified.

1. The rising of the mercury presages, in general, fair weather; and its falling, foul weather; as rain, snow, high winds, and storms. When the surface of the mercury is convex, or stands higher in the middle than at the sides, it is a sign the mercury is then in a rising state; but if the surface be concave or hollow in the middle, it is then sinking.

2. In very hot weather, the falling of the mercury indicates thunder.

3. In winter, the rising presages frost: and in frosty weather, if the mercury falls three or four divisions, there will be a thaw. But in a continued frost, if the mercury rises, it will certainly snow.

4. When foul weather happens soon after the depression of the mercury, expect but little of it: on the contrary, anticipate but little fair weather when it proves fair shortly after the mercury has risen.

5. In foul weather, when the mercury rises much and high, and so continues for two or three days before the bad weather is entirely over, then a continuance of fair weather may be expected.

6. In fair weather, when the mercury falls much and low, and thus continues for two or three days before the rain comes, then much wet may be expected, and probably high winds.

7. The unsettled motion of the mercury denotes unsettled weather.

8. The words engraved on the scale are not so much to be attended to as the rising and falling of the mercury: for if it stand at *much rain*, and then rises to *changeable*, it denotes fair weather, though not to continue so long as if the

* See Conversation VII.—Of Astronomy. Note p. 126.

mercury had risen higher. If the mercury stands at fair, and falls to changeable, bad weather may be expected.

9. In winter, spring, and autumn, the sudden falling of the mercury, and that for a large space, denotes high winds and storms; but in summer it presages heavy showers, and often thunder. It always sinks lowest of all for great winds, though not accompanied with rain; but it falls more for wind and rain together than for either of them alone.

10. If, after rain, the wind change into any part of the North, with a clear and dry sky, and the mercury rises, it is a certain sign of fair weather.

11. After very great storms of wind, when the mercury has been low, it commonly rises again very fast. In settled fair weather, except the barometer sink much, expect but little rain. In a wet season, the smallest depressions must be attended to; for when the air is much inclined to showers, a little sinking in the barometer denotes more rain. And in such a season, if it rise suddenly fast and high, fair weather cannot be expected to last more than a day or two.

12. The greatest heights of the mercury are found with easterly and north-easterly winds; and it may often rain or snow, the wind being in these points, while the barometer is in a rising state, the effects of the wind counteracting. But the mercury sinks for wind as well as rain in all other points of the compass.

QUESTIONS FOR EXAMINATION.

How is the height of the atmosphere discovered? — What is the specific gravity of the air when the barometer stands at 30 inches? — Is the atmosphere equally dense at all heights? — What is the height of the atmosphere estimated at? — Is the barometer applied to anything else besides that of showing the changes in the pressure of the atmosphere? — How much is it ascertained that the mercury of the barometer falls in ascending an eminence of 100 feet perpendicular? — Can you repeat the lines from Lofft's Eudosia which describe the pressure of the atmosphere on the human body? — How much weight does a full-grown person sustain from the pressure of the atmosphere? — What does the rising of the mercury presage? — What does its falling denote? — According as the mercury stands convex or concave, what weather may be expected? — What does the falling of the mercury indicate in very hot weather? — What does its rising indicate in winter? — If the mercury rises in a continued frost, what may be expected? — When may bad, and when fair weather be expected? — When may a continuance of fair weather be expected? — When may much wet be expected? — In examining the scale, what is to be attended to? — When may high winds, and when heavy showers be expected? — What is the sign of fair weather? — On what occasions is the mercury the highest?

CONVERSATION XXI.

OF THE THERMOMETER.

Father. As the barometer is intended to measure the different degrees of density of the atmosphere, so the thermometer is designed to mark the changes in its temperature, with regard to heat and cold: like the term barometer it is

derived from two Greek words, *thermos* (θερμος), "heat," and *metron* (μετρον), "a measure."

Em. Is there any difference between the thermometer that is attached to the barometer, and that which hangs out of doors?

Fa. No; they are both made by the same person, and on the same principle, and are intended to exhibit the same effects. But for the purposes of accurate observation, it is usual to have two instruments; one attached to, or near, the barometer, and the other out of doors; to which neither the direct nor reflected rays of the sun should ever come. Though my thermometers are both of the same construction, and such as are principally used in this country, yet there are others made of different materials, and upon different principles.

Ch. Does not this thermometer consist of mercury enclosed in a glass tube fixed to a graduated frame?

Fa. That is the construction of Fahrenheit's thermometer: but when these instruments were first invented, about 200 years ago, air, water, spirits of wine, and then oil, were employed; but these have given way to quicksilver, which is considered as the best of all the fluids, being highly susceptible of expansion and contraction, and capable of exhibiting a more extensive scale of heat. Fahrenheit's thermometer, invented about 1726, is chiefly used in Great Britain, and Reaumur's, invented about 1730, is used on the continent.

Em. Is not this the principle of the thermometer—that the quicksilver expands by heat, and contracts by cold?

Fa. It is. Place your thumb on the bulb of the thermometer.

Em. The quicksilver gradually rises.

Fa. And it will continue to rise till the mercury and your thumb are of equal heat. Now you have taken away your hand, you perceive the mercury is falling as fast as it rose before.

Ch. Will it come down to the same point at which it stood before Emma touched it?

Fa. It will; unless, in this short space of time, there has been any change in the surrounding air. Thus the thermometer indicates the temperature of the air, or, in fact, of any body with which it is in contact. Just now it was in contact with your thumb, and it rose, in the space of a minute or two, from 56° to 62°: had you held it longer on it, the mercury

would have risen still higher. It is now falling. Plunge it into boiling water,* and you will find that the mercury rises to 212°. Afterwards, you may place it in ice, in its melting state, and it will fall to 32°.

Em. Why are these particular numbers fixed upon?

Fa. You will not perhaps be satisfied if I tell you, that the only reason why 212 was fixed on to mark the heat of boiling water, and 32 to show the freezing point, was, because it so pleased M. Fahrenheit. This, however, was the case.

Ch. I can easily conceive that, at the same degree of cold, water will always begin to freeze; but surely there are different degrees of heat in boiling water, and therefore it should seem strange to have only one number for it.

Fa. In an open vessel, boiling water is always of the same heat; that is, provided the density of the atmosphere be the same; and though you increase your fire in a tenfold proportion, yet the water will never be a single degree hotter; for the superabundant heat, communicated to the water, flies off in the form of steam or vapour.

Em. But suppose you confine the steam?

Fa. Before I should attempt this, I must be provided with a strong vessel, or, as you have seen under the description of the steam-engine, it would certainly burst. But in a vessel proper for the purpose, water has been made so hot as to melt solid lead.

Ch. Will you explain the construction of the thermometer?

Fa. A B represents a glass tube: the end A is blown into a bulb, and this, with a part of the tube, filled with mercury. In good thermometers the upper part of the tube approaches to a perfect vacuum, and of course the end B is hermetically sealed. If the tube be now placed in pounded ice, the mercury will sink to a certain point, x, which must be marked on the tube; and on the scale opposite to this point 32 must be placed, which is called the freezing point. Then, if it be immersed in boiling water, the mercury will rise, and, after a few minutes, will become stationary. Against

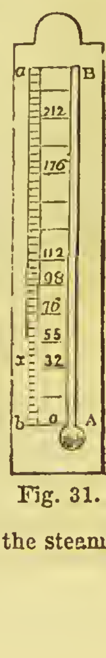


Fig. 31.

* This should be done very gradually, by holding it some time in the steam, to prevent its breaking by the sudden heat.

the point to which it rises make another mark, and write on the scale 212, for the heat of boiling water. Between these points let the scale be divided into 180 equal parts.

Em. Why 180 parts?

Fa. Because you begin from 32; and if you subtract that number from 212, the remainder will be 180. Also below 32, and above 212, set off more divisions on the scale, equal to the others. The scale is finished when you have written against 0, called zero, *extreme cold;* against 32, *freezing point;* against 55, *temperate heat;* against 76, *summer heat;* against 98, *blood heat;* against 112, *fever-heat;* against 176, *spirits boil;* and against 212, *water boils.*

Em. You said that the scale was to be divided higher than boiling water; but without mentioning the extent.

Fa. The utmost extent of the *mercurial* thermometer, both ways, are the points at which quicksilver boils and freezes: beyond these, it can be no guide. Now, the degree of heat at which mercury boils is 600, and it freezes when it is brought down as low as 39° or 40° below 0; consequently the whole extent of the mercurial thermometer is 640 degrees.

Ch. I have been trying, Papa, to guess the derivation of the word *hermetically*, which you have just used, and which you also used in describing the barometer; but I cannot.

Fa. I dare say not; for there is a question as to its derivation: it is thought to be derived from the Egyptian Hermes, who was considered the originator of chemistry, which from him was called the *Hermetic art;* whence heating the neck of a glass tube so as to twist it till it is air-tight, is said to have applied the "seal of Hermes," or to be *hermetically sealed:* others derive it from the originator of the science of Alchemy, which was also called the *Hermetic art*, one Hermes Trismegistus, a man of doubtful existence.

QUESTIONS FOR EXAMINATION.

To what is the thermometer applied? — How is it constructed? — How were thermometers formerly made? — Upon what principle does the mercurial thermometer depend? — What does the thermometer indicate? — According to Fahrenheit's thermometer, what is the freezing point, and the point of boiling water? — Is the heat of boiling water always the same? — Look to fig. 31, and explain the construction and graduation of the thermometer. — What is the utmost extent of the mercurial thermometer, and why?

CONVERSATION XXII.

THE THERMOMETER—*continued*.

Charles. Is quicksilver, when frozen, a solid metal, like iron and other metals?

Fa. It is thus far similar to them, that it is malleable, or will bear hammering; and when it boils, it goes off in vapour, like boiling water, but much slower. Hence it has been inferred that all bodies in nature are capable of existing either in *a solid*, *fluid*, or *aeriform* state, according to the degrce of heat to which they are exposed.

Em. I understand that water may be either solid, as ice, or in its fluid natural state, or in a state of vapour or steam.

Fa. I do not wonder that you call the fluid state of water its natural state, because we are accustomed in general to see it so; and when it is frozen into ice, there appears to us, in this country, a violence committed upon nature. But if a person from the West or East Indics, who had never seen the effects of frost, were to arrive in Great Britain during a severe and long continued one, such as formerly congealed the surface of the Thames, he might conclude, unless he were told to the contrary, that ice was some mineral, and naturally solid.

Em. Docs it never freeze in the East or West Indies?

Fa. It seldom freezes, unless in very elcvated situations, within 35 dcgrees of the cquator, North and South: it scarcely ever hails in latitudes higher than 60°. In our own climate, and indeed in all others between 35° and 60°, it rarely freezes till the sun's meridian altitude is less than 40 degrecs. The coldest part of the 24 hours is generally about an hour before sunrise; and the warmest part of the day is usually between two and four o'clock in the afternoon.

Ch. Are there no degrees of heat higher than that of boiling mercury?

Fa. Yes; a great many. Brass will not melt till it is made more than six times hotter than boiling mercury: and to melt cast iron requires a heat more than six times greater than is rcquired to melt brass.

Em. By what kind of thermometer are these degrees of heat measured?

Fa. The ingenious Mr. Wedgewood invented a thermometer for measuring the degrees of heat up to 32,277° of Fahrenheit's scale.

Ch. Can you explain the structure of his thermometer?

Fa. All argillaceous bodies, or bodies made of clay, are diminished in bulk by the application of great heat. The diminution commences at a dull red heat, and proceeds regularly, as the heat increases, till the clay is vitrified, or transformed into a glassy substance. This is the principle of Mr. Wedgewood's thermometer, and he divides it into 240°.

Em. Is vitrifieation the limit of this thermometer?

Fa. Certainly: the construction and application of this instrument is extremely simple; and it marks all the different degrees of ignition from the red heat, visible only in the dark, to the heat of a wind furnace. It consists of two rulers fixed on a plane, a little farther asunder at one end than at the other, leaving a space between them. Small pieces of alum and clay, mixed together, are made just large enough to enter at the wide end: they are then heated in the fire with the body, whose heat is to be ascertained. The fire, according to its heat, contracts the earthy body, so that, being applied to the wide end of the gauge, it will slide on towards the narrow end, less or more, according to the degree of heat to whieh it has been exposed.*

Each degree of Mr. Wedgewood's thermometer answers to 130 degrees of Fahrenheit; and he begins his seale from red-heat fully visible in daylight, which he found to be equal to 1077.5° of Fahrenheit's scale, if it eould be carried so high: but the instruments for measuring the heat of furnaces, &c., are ealled *pyrometers*, which we shall deseribe more at large presently.

In the next page is a small scale of heat, as it is applicable to a few bodies.

* We have, in the former parts of this work, observed, that all bodies are expanded by heat. The diminution of the argillaceous substances made use of by Mr. Wedgewood *appears* to be an exception; but as the contraction of these does not commence till they are exposed to a red heat, it may probably be accounted for, from the expulsion of the fluid particles, rather than from any real contraction in the solids.

SCALE OF HEAT.

			Fahrenheit.
Extremity of Wedgewood's scale	240°	which answers to	32,277°
Cast iron melts	160		21,877
Fine gold melts	32		5,237
Fine silver melts	28		4,717
Brass melts	21		3,807
Red heat visible by day	0		1,077
Mercury boils			600
* Lead melts			540
* Bismuth melts			460
* Tin melts			408
Milk boils			213
Water boils			212
Heat of the human body			92 to 97
Water freezes			32
Milk freezes			30
A mixture of snow and salt sinks the thermometer to			0
Mercury freezes			— 40

Ch. You said that Reaumur's thermometer was chiefly used abroad. What is the difference between that and Fahrenheit's?

Fa. Reaumur places the freezing point at 0, or zero; and each degree of his thermometer is equal to $2\frac{1}{4}$ or $\frac{9}{4}$ degrees of Fahrenheit's.

Em. What does he make the heat of boiling water?

Fa. Having fixed his freezing point at 0, and making one of his degrees equal to $2\frac{1}{4}$ of Fahrenheit, the heat of boiling water must be at 80°.

Ch. Let me see. The number of degrees between the freezing and boiling points on Fahrenheit's thermometer is 180, which divided by $2\frac{1}{4}$, or 2.25, gives 80 exactly.

Fa. You have here a rule, by which you may always convert the degrees of Fahrenheit into those of Reaumur. "Subtract 32 from the given number, and multiply by the fraction $\frac{4}{9}$." Tell me now, Emma, what degree on Reaumur's scale answers to 167° of Fahrenheit.

Em. Taking 32 from 167, there remains 135, which, multiplied by 4, gives 540; and this divided by 9 gives 60. So that 60° of Reaumur answer to 167° of Fahrenheit.

Ch. How shall I reverse the operation, and find a number

* If these three metals be mixed together by fusion in the proportion of 8, 5, and 3, the mixture will melt at a temperature below that of boiling water.

on Fahrenheit's scale that answers to a given one on Reaumur's?

Fa. Multiply the given number by the fraction $\frac{9}{4}$, and add 32 to the product. Tell me what number on Fahrenheit's scale answers to 40 on Reaumur's.

Ch. If I multiply 40 by 9, and divide the product by 4, I get 90; to which if 32 be added, the result is 122: this answers to 40 on Reaumur's scale. But what is a *register-thermometer*, Papa?

Fa. Register-thermometers are those that indicate how high or how low the thermometer has risen or fallen: they are very useful in hot-houses, and for ascertaining the temperature during the night. One invented by Mr Six, of Colchester, has a small index of iron wire capped with enamel, which lies in the vacuum of the tube, upon the mercury, and as far as the mercury rises, the index is pushed on, and when the mercury retires, the index is left at the extreme height it may have risen during the night: it is re-set by applying outside a magnet, which attracts the iron wire, and enables you to draw it down to the mercury. The one invented by Dr. Rutherford lies in the *spirit*, which he uses instead of mercury, and which marks how low the spirit has fallen, where it remains; this is re-set by inclining the thermometer, so that the index may run down to the edge of the spirit. These thermometers are horizontal in their construction.

QUESTIONS FOR EXAMINATION.

Can quicksilver be compared with other metals? — Are all bodies in nature capable of existing in the solid, fluid, and aeriform state? — In what parts of the earth does it rarely if ever freeze? — Under what circumstances does it seldom freeze here? — What is the coldest, and what is the warmest part of the 24 hours? — Does brass require a great heat to melt it? — Can heat higher than boiling mercury be ascertained by any mode? — What is the construction of Wedgewood's thermometer? — How is it used? — To how many degrees of Fahrenheit does one of Wedgewood's answer? — What is the difference between Reaumur's and Fahrenheit's thermometer? — How many degrees of Fahrenheit make one of Reaumur's? — What is the rule for converting the degrees of Fahrenheit into those of Reaumur? — How is the operation reversed and the degrees on Reaumur converted into those of Fahrenheit?

CONVERSATION XXIII.

OF THE PYROMETER AND HYGROMETER.

Father. To make our description of philosophical instruments more perfect, I shall to-day show you the construction and uses of the pyrometer and hygrometer, and conclude to-morrow with an account of the rain-gauge.

Em. What do you mean by a pyrometer?

Fa. It is a Greek word, compounded of *pyr* (πυρ), "fire," and *metron* (μετρον), "a measure," and signifies a fire-measurer. The pyrometer is a machine for measuring the expansion of solid substances, particularly metals, by heat. This instrument will render the smallest expansion sensible to the naked eye.

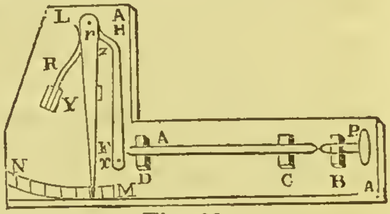


Fig. 33.

Ch. Is all this apparatus necessary for the purpose?

Fa. This, as far as I know, is one of the most simple pyrometers; and, as it admits of an easy explanation, I have chosen it in preference to a more complicated instrument, which might be susceptible of greater nicety.

To a flat piece of mahogany, A A, are fixed three studs, B, C, and D, and at B there is an adjusting screw, P: H F is a lever, turning very easily on the pivot x; and L S is an index turning on L, and pointing to the scale M N: R is part of a watch spring, fixed at Y, and pressing gently upon the index, L S. Here is a bar of iron, at the common temperature of the surrounding air: I lay it in the studs C and D, and adjust the screw P so that the index L S may point to 0 on the scale.

Ch. The bar cannot expand without moving the lever F H; the crooked part of which pressing upon L S, that also will be moved if the bar lengthens.

Fa. Try the experiment. Friction, you know, produees heat. Take the bar out of the studs; rub it briskly; and then replace it.

Em. The index L S has moved to that part of the scale which is marked 2: it is now going back. How do you calculate the length of the expansion?

Fa. The bar pressed against the lever F H at F, and that

again presses against L S at L; and hence they both act as levers.

Ch. And they are levers of the third kind; for, in one case, the fulcrum is at x, the power at F, and the point z to be moved may be considered as the weight: in the other, L is the fulcrum, the power is applied at r, and the point S is to be moved.*

Fa. The distance between the moving point F and H is 20 times greater than that between x and F: the same proportion holds between L S and L r: from this you will get the spaces passed through by the different points.

Em. Then, as much as the iron bar expands, so much will it move the point F, and of course the point z will move 20 times as much; so that if the bar lengthen $\frac{1}{10}$th of an inch the point z would move $\frac{20}{10}$ths, or two inches. By the same rule the point S will move through a space 20 times as great as the point r.

Fa. There are two levers, then; each of which gains power or moves over spaces in the proportion of 20 to 1; consequently, when united, as in the present case, into a compound lever, we multiply 20 by 20, which make 400; and therefore, if the bar lengthen $\frac{1}{10}$th of an inch, the point S must move over 400 times that space, or 40 inches. But, suppose it only expands $\frac{1}{400}$th part of an inch, how much will S move?

Ch. One inch.

Fa. But every inch may be divided into tenths, and consequently, if the bar lengthen only the $\frac{1}{4000}$th part of an inch, the point S will move through the tenth part of an inch, which is very perceptible. In the present case, the point S has moved two inches; therefore the expansion is equal to $\frac{2}{400}$ths, or $\frac{1}{200}$th part of an inch. An iron bar, three feet long, is about $\frac{1}{70}$th part of an inch longer in summer than in winter.†

Ch. I see that by increasing the number of levers, you might carry the experiment to a much greater degree of nicety.

Fa. Certainly: pyrometers are of various forms, but the most perfect are those of Ferguson, De Sue, and Ramsden;

* For an account of the different levers, see Conversation XV. and XVI. of Mechanics.

† The ratio of expansion of metallic rods of the same diameter, placed in boiling water, is found to be, in brass 94, iron 73, lead 154, and silver 81.

to these may be added that of Wedgewood previously described, and the platina pyrometers of Morveau, and of Professor Daniell. Well; let us now proceed to the hygrometer, which is an instrument contrived for measuring the different degrees of moisture in the atmosphere, it is derived from the Greek *hygros* (ὑγρος), "moist," and *metron* (μετρον), "a measure."

Em. I have a weather-house, which I bought at the fair, tells me this: for if the air is very moist, and thereby denotes wet weather, the man comes out; and in fair weather, when the atmosphere is dry, the woman makes her appearance.

Ch. How is the weather-house constructed?

Fa. The two images are placed on a kind of lever, which is sustained by catgut; and catgut is very sensible to changes of the atmosphere, twisting and shortening by moisture, and untwisting and lengthening as it becomes dry. On the same principle is constructed another hygrometer. A B is a catgut string, suspended at A with a little weight B, that carries an index C, round a circular scale, D E, on an horizontal board or table: for as the catgut becomes moist, it twists itself, and untwists when it approaches to a dry state.

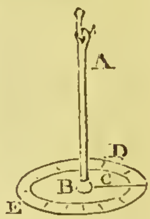


Fig. 33.

Em. Then the degrees of moisture are shown by the index, which moves backwards and forwards by the twisting and untwisting of the catgut. Do all kinds of string twist with moisture?

Fa. Yes. Take a piece of common packthread, and on it suspend a pound weight in a vessel of water, and you will see how soon the two strings are twisted round one another.

Ch. I recollect that the last time the lines for drying linen were hung out in the garden, they appeared to be much looser in the evening than they were next morning; so that I thought some person had been altering them. A sudden shower of rain has produced the same effect in a striking manner.

Em. Sometimes when sudden damp weather has set in, the string of the harp has snapped when no person has been near it.

Fa. These are the effects produced by the moisture of the air: the damp of night always shortens hair and hempen lines: and, owing to the changes to which the atmosphere in our

climate is liable, the harp, violin, &c., that are put in tune one day, will need some alteration before they can be used the next.

Here is a sensible and very simple hygrometer: it consists of a piece of whipcord, or catgut, fastened at A, and stretched over several pulleys, B, C, D, E, F: at the end is a little weight, *w*, to which is an index pointing to a graduated scale.

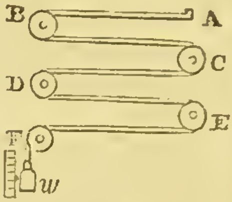


Fig. 34.

Ch. Then, according to the degree of moisture in the air, the string shortens or lengthens, and of course the index points higher or lower.

Fa. Another kind of hygrometer consists of a piece of sponge, E, prepared and nicely balanced on the beam *x y*, and the fulcrum *z*, lengthened out into an index pointing to a scale, A C.

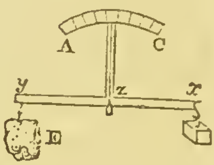


Fig. 35.

Em. Does the sponge imbibe moisture sufficiently to become a good hygrometer?

Fa. Sponge of itself will answer the purpose; but it is made much more sensible in the following manner.

After the sponge is well washed from all impurities, and dried again, it should be dipped into water or vinegar, in which common salt, salt of tartar, or almost any other salt, has been dissolved, and then suffered to dry, when it should be accurately balanced.

Ch. Do the saline particles in damp weather imbibe the moisture, and cause the sponge to preponderate?

Fa. They do. Instead of sponge, a scale may be hung at E, in which must be put some kind of salt that has an attraction for the watery particles floating in the air. Sulphuric acid may be substituted for salt; but this is not fit for your experiments; because were you to spill a little it would destroy your clothes; otherwise it makes a very sensible hygrometer.

Em. I have heard the cook complain of the damp weather, when the salt becomes wet by it.

Fa. I dare say you have: the salt-box in the kitchen is not a bad hygrometer: yet for accurate observations, neither deliquescing salts, nor any absorbing substances, nor the torsion or twisting of cords or fibrous matter, are to be relied on. Neither Saussure's hygrometer of a human hair properly prepared;

nor De Luc's hygrometer of a thin piece of whalebone, both of which act by absorption, have been proved to answer. The above means give rough indications of variations in the humidity of the air; but the principle of *condensation* has been proved to be much more efficient; and you gave me the other day, when it was so oppressively hot, an exact illustration of it. You remember then asking for a glass of cold spring water; and a little while after it was placed on the table, the outer surface of the glass became covered with a heavy dew or vapour.

Ch. What was the cause of this, papa?

Fa. The higher the temperature, the greater the amount of water air can hold in solution. The water was colder than the air, and reduced its temperature to that point at which it became saturated; hence it began to deposit the vapour which it contained. This temperature is called the *dew-point*, because it is that at which dew begins to be formed. We can at any time determine the dew-point of the air, by placing some water of the same temperature as the air in a glass, adding ice-cold water in small quantities at a time, and noting the exact degree at which a thermometer immersed in the water stands, at the very moment at which the dew begins to form upon the outside of the glass. The difference, then, between the temperature of the air and that of the water in the glass, when the dew begins to be formed, will afford an indication of the dryness of the air, or of its remoteness from the state of complete saturation; and as tables have been composed, showing the quantity of water present in the air at different dew-points, the simple determination of the latter will enable us at once to ascertain this quantity.

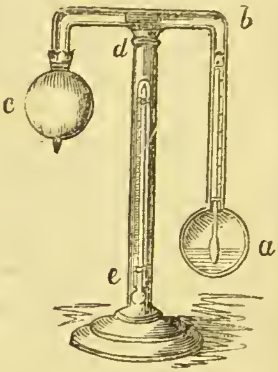
Ch. Is the dew which is deposited upon our grass-plat of the same origin as that upon the glass?

Fa. It is. During the day the earth receives heat from the sun, but during the night it gives off this heat by radiation to the sky, and thus reduces the temperature of the air with which it is in immediate contact to its dew-point. The amount of dew deposited is proportionate to this cooling process; thus, in cloudy nights, when the free cooling of the surface of the earth is prevented by the clouds, which reflect the heat again towards the earth, but little dew is formed;

whilst, in clear nights, the quantity of it is large, on account of the much greater reduction of temperature from the more free radiation.

Ch. I have heard of Daniell's hygrometer—how does this act?

Fa. Upon the principle of condensation, which we saw exemplified in the case of the glass of water. The instrument consists of a bulb of black glass *a* connected to another bulb *c* by a bent tube. Enough sulphuric ether to fill three-fourths of the ball *a* is introduced into it; a delicate thermometer is fixed in the limb *a b;* and as much of the atmospheric air as possible is expelled from the tube before it is closed when made. The bulb *c* is covered with muslin; the whole is supported upon a brass stand *d e,* to which another delicate thermometer is attached. The instrument is used thus: the ether is first collected in the bulb *a* by inclining the tube, so that this bulb is held lowermost; it is then placed upright, the temperature of the surrounding air is noted in the outside thermometer; ether is next poured upon the muslin at *c,* and the cold resulting from its evaporation causing condensation of the vapour of the ether within the bulb, produces rapid evaporation from *a,* by which the temperature of the thermometer within it is lowered; and when the black bulb is thus cooled to the dew-point, a film of condensed vapour is deposited upon the bulb. The temperature then indicated by the thermometer within *a* at the instant at which the dew begins to be deposited forms the dew-point.



Ch. What is the wet-bulb hygrometer?

Fa. This form of instrument consists of two delicate thermometers placed side by side, the bulb of one of which is covered with muslin; this is tied round the bulb, and the end of the strip allowed to hang into a little glass vessel filled with water. Evaporation then goes on from the muslin covering the bulb, but this does not become dry, because more water ascends by capillary attraction through the muslin, to replace that lost. As the evaporation continues,

the temperature of the thermometer becomes lowered by the cold produced. Presently the diminution of temperature attains its maximum. The difference between the heights of the two thermometers indicates the comparative states of dryness of the air. If the air be moist, less evaporation will take place, and the depression of temperature of the thermometer in the wet bulb will be but slight; whilst, if the air be very dry, the evaporation will be very great and rapid, and the diminution of temperature great also.

QUESTIONS FOR EXAMINATION.

What do you mean by a pyrometer?—Explain the structure and use of that represented by fig. 32.—For what is the hygrometer used?—Upon what principle does the common weather-house act?—Can you tell how the hygrometer (fig. 33) acts?—What effect has moisture on pack-thread, cat-gut, &c.?—Show me how the hygrometer (fig. 34) acts.—How can sponge be made into an hygrometer?—How is the principle of condensation applied to hygrometry?—What is meant by the dew-point?—How is the dew-point determined?—How is dew formed?—What is the principle of Daniell's hygrometer?—What is the wet-bulb hygrometer?—Explain to me the principle of this?

CONVERSATION XXIV.

OF THE RAIN-GAUGE.

Father. We will now describe the rain-gauge, an instrument intended to show the height or quantity of rain that falls in any particular place; it has various names given it by scientific men; as the *Ombrometer*, from the Greek *ombros* (ὄμβρος), "rain or a shower," and *metron* (μετρον), "a measure;" or the *Pluviometer*, from the Latin *pluvius*, "rainy;" or the *Udometer*, from the Latin *udus*, "wet."

Ch. Does the rain-gauge measure accurately the quantity of rain that falls?

Fa. It shows the height to which the rain would rise on the place where it is fixed, if there were no evaporation, and if none of it were imbibed by the earth. The one we had consisted of a funnel, A communicating with a cylindric tube B. The diameter of the funnel was exactly 12 inches, and that of the tube was 4 inches. Tell me, Emma, what proportion the area of the former has to that of the latter.

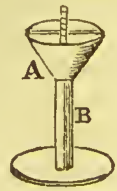


Fig. 36.

Em. I remember that all plane surfaces bear the same proportion to one another as are the squares of their diameters. Now the square of 12 is 144, and the square of 4 is 16; therefore, the proportion of the area of the funnel is to that of the tube as 144 to 16.

Fa. But 144 may be divided by 16 without leaving a remainder.

Ch. Yes; 9 times 16 make 144; consequently, the proportion is as 9 to 1; that is, the area of the funnel is 9 times greater than that of the tube.

Fa. If, then, the water in the tube be raised 9 inches, the depth of rain fallen will, in the area of the funnel, which is the true gauge, be only one inch.

Em. Does the little graduated rule mark the rise?

Fa. Yes, it does. It is a floating index, divided into inches.

Em. If, then, the float be raised one inch, is the depth of water reckoned only $\frac{1}{9}$th of an inch?

Fa. Yes: and each nine inches in length being divided into 100 equal parts, the fall of rain can be readily estimated to the $\frac{1}{900}$th part of an inch. Rain-gauges should be varnished or well painted, and as much water should be first poured in as will raise the float to such a height that the 0, or zero point on the ruler, may coincide with the edge of the funnel.

Ch. This is not like your present rain-gauge.

Fa. That which I now use, though somewhat more difficult of explanation, is a much cheaper instrument; it may be made without the bottle, for a single shilling. It consists of a tin funnel; the area of the top of which is exactly 10 square inches, and the tube, about 5 or 7 inches long, passes through a cork fixed in a quart bottle.

Em. Is there any particular proportion between the area of the funnel and that of the bottle?

Fa. No, it is not necessary; for in this the weight of the rain is calculated by its weight compared with the area of the funnel, which is known. For every ounce of water, I allow 173 parts of an inch for the depth of the rain fallen. Thus, the last time I examined the bottle, I found that the water weighed exactly 6 ounces; and 6 multiplied by 173 gives 1038; that is, the rain fallen in the preceding month was equal to rather more than an inch in depth. In the month of June

the rain collected in the gauge weighed $11\frac{1}{2}$ ounces, which is nearly equal to 2 inches in depth.

Ch. Pray explain the reason for multiplying the number of ounces by the decimals ·173.

Fa. Every gallon of pure rain water contains 231 cubic inches, and weighs 8lb. 5 oz. $\frac{2}{3}$ avoirdupois; consequently every ounce of water is equal to ·173 cubic inches; but the area of the funnel is 10 square inches, and 10 multiplied by ·173, the depth of the rain fallen, is equal to 1·73.

You have now a pretty full account of all the instruments necessary for judging of the state of the weather, and for comparing, at different seasons, the various changes as they happen.

Em. Yes; the *barometer*, informs us of the weight or density of the atmosphere; the *thermometer*, shows its heat; the *hygrometer*, what degree of *moisture* it contains; and by the *rain-gauge* we learn how much rain falls in a given time.

Fa. The rain-gauge must be fixed at some distance from all buildings which might in any way shelter it from driving winds; and the height at which the surface of the funnel is from the ground must be ascertained.

Ch. Does it make any difference in the quantity of rain collected if the gauge stands on the ground or some feet above it?

Fa. Very considerable: as that which I have described is a cheap instrument, one may be placed on the top of the house, and the other on the garden wall; and you will find the difference much greater than you would imagine.

QUESTIONS FOR EXAMINATION.

For what purpose is the rain-gauge used? — How does that act which is represented in fig. 36? — What proportion do all plane surfaces bear to one another? — How is the rise of the water noted? — To what degree of accuracy can the quantity of rain be measured? — Can you explain the structure of the other rain-gauge? — Name the different instruments used in comparing the changes of the atmosphere. — How should the rain-gauge be fixed? — Is there any difference in the quantity of rain collected, whether the gauge stand on the ground or on a building considerably above the surface of the earth?

SOME OF THE LEADING DEFINITIONS IN PNEUMATICS, WHICH IT IS RECOMMENDED THAT THE PUPILS SHOULD COMMIT TO MEMORY.

PNEUMATICS.

1. The science of Pneumatics treats of the mechanical properties of air.
2. Air is a solid and material substance as well as water and other fluids.
3. The invisibility of the air is owing to its transparency.
4. Air possesses weight, compressibility and elasticity.
5. The pressure of the atmosphere is equal to the pressure of a column of water 32 or 33 feet high, or to a column of mercury about 30 inches high.
6. The Torricellian experiment proves there is no such thing as suction.
7. The pressure of the air is shown by various experiments.
8. The weight of the air is demonstrated by experiments.
9. The density and elasticity of the air are in proportion to the force that compresses it.
10. The elasticity of the air in the human body is shown by experiments on the air-pump.
11. The operation of cupping depends on the elasticity of the air in the body.
12. The density of the air diminishes upwards.
13. The air-pump is a machine for exhausting the air from vessels.
14. A vacuum is a space emptied of air.
15. Artificial fountains are made by means of compressed air.
16. The height to which artificial fountains ascend depends on the quantity of air forced into the vessel.
17. The ascent of smoke and vapours depends on the density of the air.
18. A piece of cork and a piece of lead exactly balanced in the air, being introduced under the receiver of an air-pump, and the air taken away, the cork will appear the heaviest body.
19. The effects of the air-gun depend on the elasticity and compression of air.
20. Air-guns will answer the same purposes as fowling-pieces.
21. The air presses upon every body immersed in it, and on every side.
22. Air is the medium of sound, and sound is increased in proportion to the density of the air.
23. Thunder is produced by the concussion of two bodies of air.
24. All sonorous bodies are elastic, and their parts are made to vibrate by percussion.
25. The vibrations of a bell are invisible.
26. Sound can be heard at a great distance when it passes over water.
27. Sound travels at the rate of 1142 feet in a second of time: hence is easily found the distance of a storm when accompanied by thunder and lightning, or the distance of a ship in distress by the firing of her guns.
28. Sound is the effect produced on the ear by the undulations of the air.
29. When these undulations strike against any surface adapted to the purpose and are reflected back, an echo is produced.
30. For an echo to be heard, the ear must be in a line of reflection.
31. There can be no echo unless the direct and reflected sounds follow one another at a sufficient interval of time.
32. For an echo to be distinct, the reflected sound must travel over, at least 127 feet more than the direct.
33. If many syllables are to be repeated, the distance must be increased in proportion to the number of syllables.

34. The echo has been applied to the measuring of inaccessible distances.

35. Water is the best conductor of sound, and next to this is stone.

36. Wood is sonorous, and produces a most agreeable tone, which renders it so well adapted for musical instruments.

37. The notes upon a violin depend upon the different lengths of the strings, which are varied by the fingers of the musician.

38. All the strings of an Eolian harp will, if set to the same note, vibrate by striking one only.

39. Air in motion constitutes wind.

40. The principal cause of wind is heat communicated by the sun.

41. The smoke-jack acts by the force of the air of the room, which being rarefied ascends the chimney and strikes upon the vanes of the jack.

42. The direction of the wind is denominated from that quarter from which it blows.

43. There are three kinds of winds; the constant, the periodical, and the variable.

44. On the sea-coasts between the tropics the wind blows towards the shore in the day, and towards the sea by night.

45. Machines used for measuring the force of the wind are called wind-gauges.

46. The force of the wind increases as the square of the velocity.

47. Barometers are instruments for measuring the weight or pressure of the atmosphere.

48. The Torricellian vacuum is the empty space in the upper part of the barometer tube.

49. The standard altitude of the mercury fluctuates in this country between 28 and 31 inches.

50. Within and near the tropics there is but little variation in the height of the mercury of the barometer in all weathers.

51. The vernier is an instrument to show the fluctuation of the mercury to the hundredth part of an inch.

52. Air is about 800 times lighter than water.

53. The barometer has been applied to the measuring of altitudes.

54. A common sized person bears from the pressure of the air a weight equal to nearly 13 tons.

55. The thermometer is intended to mark the changes in the temperature of the atmosphere.

56. The mercury or other fluids used as thermometers expand by heat and contract by cold.

57. All bodies in nature are capable of existing in a solid, fluid, and aeriform state.

58. Wedgewood's thermometer is intended to measure those degrees of heat which are above boiling mercury.

59. Each degree of Reaumur's thermometer is equal to $2\frac{1}{4}$ of Fahrenheit's.

60. The pyrometer is a machine for measuring the expansion of solid substances by heat, and is contrived to mark the smallest expansions possible.

61. The hygrometer is an instrument contrived to measure different degrees of moisture in the atmosphere.

62. The rain-gauge measures the quantity of rain fallen on one particular spot.

OPTICS.

FIRST CONVERSATION.

INTRODUCTION — OF LIGHT — THE SMALLNESS OF ITS PARTICLES—THEIR VELOCITY—THEY MOVE ONLY IN STRAIGHT LINES.

FATHER — CHARLES — JAMES.

Charles. When we were on the sea, you told us that you would explain the reason why the oar, which was straight when it lay in the boat, appeared crooked as soon as it was put into the water.

Fa. I did: but it requires some previous knowledge before you can comprehend the subject. It would afford you but little satisfaction to be told that this deception was caused by the different degrees of *Refraction* which take place in water and in air.

Ja. What do you mean by the word refraction?

Fa. *Refraction* is a term frequently used in the science of optics; and this science depends wholly on *light.*

Ja. What is light?

Fa. It would, perhaps, be difficult to give a direct answer to your question, because we know nothing of the nature of light, but by the effects which it produces. In reasoning, however, on this subject, it is generally admitted, that light consists of inconceivably small particles, which are projected, or thrown off, from a luminous body with great velocity, in all directions.

Ch. But is it true that light is *material,* that is, composed of particles of matter?

Fa. There is no proof, indeed, that light is *material,* or composed of particles of matter; and therefore I said it was *generally,* not *universally,* admitted to be so: the nature of

light has been the groundwork of two very great theories, one termed the *Undulatory Theory*, and the other the *Corpuscular Theory*. The former supposes light to consist of the undulations of the particles of some elastic and extremely rare medium, as ether, which pervades the whole universe; it obtained the support of Descartes, Hooke, Huygens, and Young, and of late years has been revived. You will understand how the particles of the ether move in undulations or waves, by recollecting the particles of water in the sea or a river, when set in motion by the wind; or the ears in a field of ripe corn, when they are acted upon by the same agent. The *Corpuscular Theory* resulted from the immortal Newton, who, in 1672, considered light to consist of inconceivably minute particles, in Latin *corpusculum*, "a small body or atom," perfectly material, though extremely subtile, passing with immense velocity, nearly 200,000 miles in a second, from luminous bodies into the eye; this theory is the base of the present system of Optics, and exclusively prevailed till lately.

Ja. Does not the light come from the sun in a somewhat similar manner that it does from a candle?

Fa. We may suppose so; but there appears to be a great difference between the two bodies. A candle, whether of wax or tallow, is soon exhausted; but philosophers have never been able to observe that the body of the sun is at all diminished by the light which it incessantly pours forth.

Ja. You say incessantly: but we see it only by day.

Ch. That is because the part of the earth which we inhabit is turned away from the sun during the night: but our midnight is mid-day to some other parts of the earth.

Fa. You are right, Charles: besides, you know that the sun is not intended merely for the benefit of this globe, but is the source of light and heat to twenty-two other planets and eighteen moons belonging to them.

Ch. You have included, I perceive, the more recently discovered little planets, denominated *Asteroids*.

Fa. I will therefore now inform you that the sun to these is the perpetual source of light, heat, and motion; and to more distant worlds it is a fixed star, appearing to some as large as Arcturus; to others no larger than a star of the sixth magnitude; and to others it must be invisible; unless the inhabitants have the assistance of glasses, or are endowed with better eyes than ourselves.

Ja. Do you know, Papa, how swift the particles of light move?

Fa. That you may easily calculate, when you know that they are only about eight minutes in coming from the sun.

Ch. And if you reckon that at the distance of ninety-five millions of miles from the earth, light proceeds at the rate, nearly, of twelve millions of miles in a minute, or at 200,000 miles in a second of time. But how do you know that it travels so fast?

Fa. It was discovered by M. Röemer, who observed that the eclipses of Jupiter's Satellites took place about sixteen minutes twenty-six seconds later, if the earth was in that part of its orbit which is furthest from Jupiter, than if it was in the opposite point of the heavens, when nearest to that planet.

Ch. I understand this. The earth may sometimes be in a line between the sun and Jupiter, and at other times the sun is between the earth and Jupiter; and therefore, in the latter case, the distance of Jupiter from the earth is greater than in the former, by the whole length of its orbit.

Fa. In this situation the eclipse of any of the satellites is, by calculation, sixteen minutes twenty-six seconds later than it would be if the earth were between Jupiter and the sun: that is, the light flowing from Jupiter's satellites is about sixteen minutes in travelling the length of the earth's orbit, or 190 millions of miles.

Ja. It would be curious to calculate how much faster light travels than a cannon-ball fired with the greatest force.

Fa. Suppose a cannon-ball to travel at the rate of twelve miles a minute; light moves a million of times faster than that; and yet Dr. Akenside conjectures that there may be stars so distant from us, that the light proceeding from them has not yet reached the earth.

> . . . . Whose unfading light
> Has travell'd the profound six thousand years,
> Nor yet arrived in sight of mortal things.

Ja. And you say the particles of light move in all directions.

Fa. Yes; take, for example, this sheet of thick brown-paper. I will make but a small pin-hole in it, and now,

through that hole, you can see all the objects, such as the sky, trees, houses, &c., as well as if the paper were not there.

Ch. Do we only see objects by means of the rays of light which come from them?

Fa. In no other way: and therefore the light that comes from the landscape which you see by looking through the small hole in the paper, must come in all directions at the same time. Take another instance. If a candle be placed on an eminence in a dark night, it may be seen all round for the space of half a mile: in other words, there is no place, within a sphere of a mile in diameter, where the candle cannot be seen; that is, where some of the rays from the small flame will not be found.

Ja. Why do you limit the distance to half a mile?

Fa. The distance, of course, will be greater or less according to the size of the candle: but the degree of light, like heat, diminishes in proportion as you go further from the luminous body.

Ch. Does it follow the same law as *gravity?*

Fa. It does: the *intensity* or degree of light decreases as the square of the distance from the luminous body increases.

Ja. Do you mean that, at the distance of two yards from a candle, we shall have four times less light than we should have if we were only one yard from it?

Fa. I do: and at three yards distance, nine times less light; and at four yards distance you will have sixteen times less light than you would were you within a yard of the object.

I have one more thing to tell you. Light always moves in straight lines.

Ja. How is that known?

Fa. Look through a straight tube at any object, and the rays of light will flow readily from it to the eye; but if the tube be bent, the object cannot be seen through it; which proves that light will move only in a straight line. So, likewise, if you have two or three pieces of mill-board, with a hole in the centre of each of them, and hold them up before a candle a little apart from each other; if the holes are in the same straight line, the light will pass through them to the wall; if they are not so, the light will be obscured.

This is plain also from the shadows which opaque bodies cast. Hold any object, such as a square board, or a book, in

the light of the sun, or a candle, the shadow caused by it will prove that light moves only in right or straight lines: for the rays pass from the light straight by the edge of the object to the extremities of the shadow.

Ch. But what, Papa, is the meaning of the word *Optics?*

Fa. It is a term applied to that part of Natural Philosophy which treats of vision or sight, being derived from the Greek word *optomai* (ὀπτομαι), "I see."

Ch. And does it not also treat of light, and the various phenomena connected with it?

Fa. Of course; I have observed it to you before.

Ch. Are there no other sources of light besides the sun?

Fa. All luminous bodies, that is, such as do not require borrowed light to be perceptible, are generally considered as such. For instance, the sun, the fixed stars, and probably the comets. Moreover, all combustible and phosphorescent bodies.

Ja. What is meant, Papa, by phosphorescent bodies?

Fa. It is well known that wood, and many other organic substances, when they decay, give off a peculiar light which is termed phosphorescent. Many insects and other animals possess this property, and I need scarcely call to your mind the pretty glow-worm, whose bright green light we have frequently had occasion to admire in our evening walks.

Other bodies become luminous when heated, rubbed, or struck; a familiar instance of which is the light produced by striking a piece of flint against a steel-blade.

Ja. What is a ray of light?

Fa. It is thought to be a stream of very minute particles emitted from *any* luminous body, and which invariably proceeds in a direct line, unless its direction be changed or stopped by some intervening object.

QUESTIONS FOR EXAMINATION.

Of what does light consist? — Are the particles of light very small? — From whence does light proceed? — Who discovered the velocity of light, and by what means was the discovery made? — How much faster does light travel than a cannon-ball? — What is Dr. Akenside's conjecture on this subject? — Repeat the lines in which it is contained. — How is it proved that the particles of light move in all directions? — In what proportion is the intensity of light reckoned? — Explain what you mean by this. — How does light move? — What experiment proves this? — Are there any other sources of light besides the sun? — What is meant by a phosphorescent body?

CONVERSATION II.

OF RAYS OF LIGHT — OF REFLECTION.

Charles. You talked, the last time we met, of the rays of light flowing or moving. What did you define a *ray of light?*

Fa. Light, you know, according to the *corpuscular* theory, is supposed to be made up of indefinitely small particles. Now, one or more of these particles in motion, from any body, is called a ray of light. If this supposition be true, that light consists of particles flowing from a luminous body, such as the sun; and that these particles are about eight minutes in coming from the sun to us: therefore, if the sun were blotted from the heavens, we should actually have the same appearance for eight minutes after the destruction of that body as we now have.

Ja. I do not understand how we could see a thing that would not exist.

Fa. The sun is perpetually throwing off particles of light, which travel at the rate of twelve millions of miles in a minute; and it is by these that the image of the body is impressed on our eye. The sun being blotted from the firmament would not affect the course of the particles that had the instant before been thrown from him; they would travel on as if nothing had happened, and, till the last particles had reached the eye, we should think we saw the sun as we do now.

Ch. Do we not actually see the body itself?

Fa. The sense of sight may, perhaps, not be unaptly compared to that of smell. A grain of musk will throw off its odoriferous particles all round, to a considerable distance; and if you or I happen to be near it, the particles which fall upon certain nerves in the nose will excite in us those sensations by which we say we have the smell of musk. In the same way particles of light are flowing in every direction from the grain of musk, some of which fall on the eye, and these excite different sensations; from which we say we see a piece of musk.

Ch. But the smell of the musk will, in time, be completely dissipated by its throwing off the fine particles; whereas a

chair or a table may throw off its rays so as to be visible, without ever diminishing in size.

Fa. True: because whatever is distinguished by the sense of smell is known only by the particles of the odoriferous body itself flowing from it; whereas a body distinguished by the sense of sight is known by the rays of light, which first fall on the body, and are then *reflected* from it.

Ja. What do you mean by being *reflected?*

Fa. If I throw this marble forcibly against the wainscot, will it remain where it struck?

Ja. No: It will *rebound*, or come back again.

Fa. What you call rebounding, writers on optics denominate *reflection.* When a body of any kind, whether it be a marble with which you play, or a particle of light, strikes against a surface, and is sent back again, it is said to be reflected. If you shoot a marble straight against a board, or any other obstacle, it comes back in the same line, or nearly so: but suppose you throw it sideways, does it return to the hand?

Ch. Let me see. I will shoot this marble against the *middle* of one side of the room from the corner of the opposite side.

Ja. You now find that, instead of coming back to your hand, it goes off to the other corner, directly opposite to the place from which you sent it.

Fa. This will lead us to the explanation of one of the principal definitions in optics—viz., *that the angle of reflection is always equal to the angle of incidence.* Do you remember what an angle is, my children?

Ch. We do: but we do not know what an angle of *incidence* is.

Fa. I said that a ray of light was a particle of light in motion: now there are *incident* rays, and *reflected* rays.

The *incident* rays are those which *fall on* the surface; and the *reflected* rays are those which are *sent off* from it.

Ch. Does the marble, *going to* the wainscot, represent the *incident* ray, and, in *going from* it, does it represent the *reflected* ray?

Fa. It does: and the wainscot may be called the reflecting surface.

Ja. Then what are the angles of incidence and reflection?

Fa. Suppose you draw the lines on which the marble passed to the wainscot, and from it again.

Ch. I will do it with a piece of chalk.

Fa. Now draw a perpendicular from the point where the marble struck the surface, that is, where your two lines meet.

Ch. I see there are two angles; and they seem to be equal.

Fa. If the experiment were accurately made, the two angles would be perfectly equal: the angle contained between the incident ray and the perpendicular is called the angle of incidence; and that contained between the perpendicular and reflected ray is called the angle of reflection.

Ja. Are these in all cases equal, if the marble be shot in any direction?

Fa. They are: and the truth holds equally with rays of light. To prove it, stand both of you in front of the looking-glass. Each of you sees himself and his companion at the same time; for the rays of light flow from you to the glass, and are reflected back again in the same lines. Now, both of you, stand on one side of the room. What do you see?

Ch. Not ourselves; but the furniture on the opposite side.

Fa. The reason of this is, that the rays of light flowing from you to the glass are reflected to the other side of the room.

Ch. Therefore, if I go to that part, I shall see the rays of light flowing from my brother: and I now see him in the glass.

Ja. And I see you.

Fa. Now, the rays of light flow from each of you to the glass, and are reflected to each other: but neither of you sees himself.

Ch. No. I will move in front of the glass: now I see myself, but not my brother; and I think I understand the subject very well.

Fa. Then explain it to me by a figure, which you may draw on the slate.

Ch. Let ab represent the looking-glass. If I stand at o, the rays flow from me to the glass, and are reflected back in the same line, because now there is no angle of incidence, and of course no angle of reflection; but if I stand at x, then the rays flow from me to the

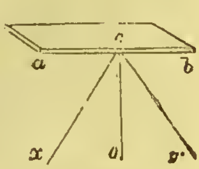


Fig. 1.

glass, but they make the angle *xcy;* and therefore they must be reflected in the line *cy*, so as to make the angle *yoc*, (which is the angle of reflection,) equal to the angle *xoc*. And if James stand at *y*, he will see me at *x*, and I, standing at *x*, shall see him at *y*.

Fa. The portion of optics peculiarly applied to the illustration of reflection is called *catoptrics,* from the Greek *catoptron* (κατοπτρον), "a mirror," a word compounded of *cata* (κατα), "from, or against," and *optomai* (οπτομαι), "I see."

QUESTIONS FOR EXAMINATION.

How is a ray of light described? — By what means do we see objects? — To what is the angle of reflection equal? — What do you mean by incident rays? — What is meant by reflected rays? — Tell me how the nature of incident and reflected rays is illustrated by the looking-glass.

CONVERSATION III.

OF THE REFRACTION OF LIGHT.

Charles. If the looking-glass stop the rays of light, and reflect them, why cannot I see myself in the window?

Fa. It is the silvering on the looking-glass which causes the reflection: otherwise the rays would pass through it without being stopped; and if they were not stopped, they could not be reflected. No glass, however, is so transparent as not to reflect some rays. Put your hand to within three or four inches of the window, and you will see clearly the image of it.

Ja. So I do; and the nearer the hand is to the glass, the more evident is the image; but it is formed on the other side of the glass, and beyond it too.

Fa. It is. This happens also in looking-glasses: you do not see yourself on the surface, but apparently as far behind the glass as you stand from it in the front. The silvering on the back of a looking-glass is an amalgam, or mixture of tin and mercury, and mercury when clean, as well as polished metallic surfaces, reflect nearly all the rays of light which fall upon them; but those surfaces that are dull and rough reflect but few. The surface of the substance rather than its nature has the greatest influence in reflection.

Whatever suffers the rays of light to pass through it, is called a *medium*. Glass, which is transparent, is a medium; so also is air: water, and indeed all fluids that are transparent, are called *media*, and the more transparent the body, the more perfect is the medium.

Ch. Do the rays of light pass through these in a straight line?

Fa. They do: but not in precisely the same direction in which they were moving before they entered it: they are *bent* out of their former course; and this is called *refraction*, which takes place at the surface of separation of the two media.

Ja. Can you explain this term more clearly?

Fa. Suppose A B to be a piece of glass, two or three inches thick, and a ray of light, *c a*, to fall upon it at *a*; it will not pass through it in the direction *c s*, but when it comes to *a*, it will be bent towards the perpendicular *a b*, and go through the glass in the course *a x*; and when it comes into the air, it will pass on in the direction *x z*, which is parallel to *c s*.

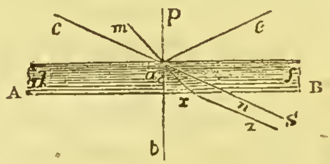


Fig. 2.

Ch. Does this happen if the ray fall perpendicularly on the glass as P *a*?

Fa. In that case there is no refraction; but the ray proceeds in its passage through the glass, precisely in the same direction as it did before it entered it; namely, in the direction P *b*.

Ja. Does refraction, therefore, take place only when the rays fall obliquely, or slantingly, on the medium?

Fa. Yes: rays of light may pass out of a rarer into a denser medium, as from air, into water or glass; or they may pass from a denser medium into a rarer, as from water into air.

Ch. Are the effects the same in both cases?

Fa. By no means: and I wish you to remember the difference. When light passes out of a rarer into a denser medium, it is drawn *to* the perpendicular: thus, if *c a* pass from air into glass, it moves, in its passage through it, in the line *a x*, which is nearer to the perpendicular *a b* than the line *a s*, which was its first direction.

But when a ray passes from a denser medium into a rarer,

it moves in a direction *farther from* the perpendicular: thus, if the ray *x a* pass through glass or water into air, it will not, when it comes to *a*, move in the direction *a m*, but in the line *a c*, which is farther than *a m* from the perpendicular *a* P.

Ja. Can you show us any experiment in illustration of this?

Fa. Yes, I can. Here is a common earthen pan; on the bottom of which I will lay a shilling, and fasten it with a piece of soft wax, so that it shall not move from its place while I pour in some water. Stand back till you just lose sight of the shilling.

Ja. The side of the pan now completely hides the sight of the money from me.

Fa. I will now pour in a pitcher of clear water.

Ja. The shilling is now visible. How is this explained?

Fa. Look to the last figure, and conceive your eye to be at *c*, A B the side of the pan, and the piece of money to be at *x*, now, when the pan is empty, the rays of light flow from *x* in the direction *x a m;* but your eye is at *c;* of course you cannot see anything by the ray proceeding along *x a m.* As soon as I put the water into the vessel, the rays of light proceed from *x* to *a;* but there they enter from a denser to a rarer medium, and therefore, instead of moving in *a m*, as they did when there was no water, they will be bent *from* the perpendicular, and will come to your eye at *c*, as if the shilling were situate at *n*.

Ja. And it appears to me to be at *n*.

Fa. Remember what I am about to tell you; for it is a kind of axiom in optics. "We see everything in the *direction* of that line in which the rays approach us last:" which may be thus illustrated:—I place a candle before the looking-glass, and if you stand also before the glass, the image of the candle appears behind it; but if another looking-glass be so placed as to receive the reflected rays of the candle, and you stand before this second glass, the candle will appear behind that; because the mind transfers every object seen along the line in which the rays came to the eye last.

Ch. If the shilling were not moved by the pouring in of the water, I do not understand how we could see it afterwards.

Fa. But you do see it now at the point *n*, or rather at the

little dot just above it, which is an inch or two from the place where it was fastened to the bottom, and from which you may convince yourself it has not moved.

Ja. I should like to be convinced of this. Will you make the experiment again, that I may be satisfied of it.

Fa. You may make it as often as you please, and the effect will always be the same: but you must not imagine that the shilling only will appear to move, the bottom of the vessel seems also to change its place.

Ja. It appears to me to be raised higher as the water is poured in.

Fa. I trust you are satisfied by this experiment now: but I can show you another equally convincing; only for this we stand in need of the sun.

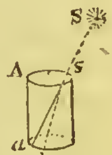


Fig. 3.

Take an empty basin or pan, A, into a dark room, having only a very small hole in the window shutter: place the basin so that a ray of light, S *s*, shall fall upon the bottom of it at *a:* here make a small mark, and then fill the basin with water. Now, where does the ray fall?

Ja. Much nearer to the side, at *b*.

Fa. I did not move the basin, and therefore could have no power in altering the course of the light.

Ch. It is very clear that the ray was refracted by the water at *s:* and I see that the effect of refraction, in this instance, has been to draw the ray nearer to a perpendicular, which may be conceived to be the side of the vessel.

Fa. The same thing may be shown with a candle in a room otherwise dark. Let it stand in such a manner so that the shadow of the side of a pan or box may fall somewhere at the bottom of it. Mark the place, and pour in water, and the shadow will not then fall so far from the side.

QUESTIONS FOR EXAMINATION.

Why does the glass in the window reflect the rays of light?—Does all glass reflect in some measure the rays of light?—In looking at a looking-glass, where is the image of yourself formed?—What is meant by a medium?—What constitutes the excellence of a medium?—How do the rays of light pass through different media?—What is meant by refraction?—When does refraction take place?—What is the rule when a ray of light passes from a rarer into a denser medium?—What is the rule when it passes from a denser into a rarer medium?—What experiment is exhibited in proof of this?—In what direction do we see anything?

CONVERSATION IV.

OF THE REFLECTION AND REFRACTION OF LIGHT.

Father. We will proceed to some farther illustrations of the laws of reflection and refraction. We will first shut out all the light except the ray that comes in at the small hole in the shutter. At the bottom of this basin, where the ray of light falls, I will lay this piece of looking-glass; and if the water be rendered in a small degree opaque by mixing with it a few drops of milk, and the room be filled with dust by any means, you will then see the refraction which the ray from the shutter undergoes in passing into the water, the reflection of it at the surface of the looking-glass, and the refraction which takes place when the ray leaves the water and passes again into the air.

Ja. Does this refraction take place in all kinds of glass?

Fa. It does: but where the glass is very thin, as in window-glass, the deviation is so small as to be generally overlooked. You may now understand why the oar in the water appears bent, though it be really straight; for, suppose A B to represent water, and *m a x* the oar, the image of the part *a x* in the water will lie above the object, so that the oar will appear in the shape *m a n*, instead of *m a x*. On this account also a fish in the water appears nearer the surface than it actually is; and a marksman shooting at it must aim below the place which it seems to occupy.

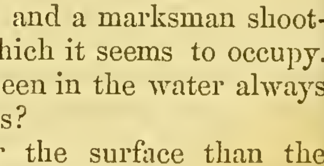


Fig. 4.

Ch. Does the image of the object seen in the water always appear higher than the object really is?

Fa. It appears one-fourth nearer the surface than the object actually is: Hence a pond or river is a third-part deeper than it appears to be, which is of importance to remember; for many a school-boy has lost his life by imagining the water into which he plunged was within his depth.

Ja. You say that when the bottom appears *one-fourth* nearer the surface than it is, the water is a *third* deeper than it seems to be; I do not understand this.

Fa. Suppose the river to be six feet deep, which is suffi-

cient to drown you or me, if we cannot swim, I say the bottom will appear to be only four feet and a half from the surface; in which case you could stand and have the greater part of your head above it. Of course it appears to be a foot and a half shallower than it is; but a foot and a half is just the *third* part of four feet and a half.

Ch. Can this be shown by experiment?

Fa. Certainly. I will take this large empty pan, and with a piece of soft wax stick a piece of money at the bottom; so that you can just see it as you stand. Keep your position, and I will pour in a quantity of water gradually. Now tell me how it appears.

Ch. The shilling rises exactly in the same proportion as the water is increased.

Fa. Recollect, then, in future, that we cannot judge of *distances* so well in water as in air.

Ja. Nor of magnitudes either, I conceive: for, in looking through the sides of a glass globe at some gold and silver fish, I thought them very large; but when I looked down upon them from the top, they appeared much smaller indeed.

Fa. Here the convex or round shape of the glass becomes a magnifier: the reason of which will be explained hereafter. A fish will, however, look larger in water than it really is.—I will show you another experiment, which depends on refraction. Here is a glass goblet, two-thirds full of water: I throw into it a shilling, put a plate on the goblet and turn it quickly over, that the water may not escape. What do you see?

Ch. There is certainly a half-crown lying on the plate; and a shilling seems swimming above it in the water.

Fa. So it appears, indeed; but it is a deception which arises from your seeing the piece of money in two directions at once, viz., through the conical surface of the water at the side of the glass, and through the flat surface at the top of the water. The conical surface, as was the case with the globular one, in which the fish were swimming, magnifies the money; but by the flat surface the rays are only refracted; on which account the money is seen higher up in the glass, of its natural size or nearly so.

Ja. If I look sideways at the money, I only see the large piece; and if only at the top, I see it in its natural size and state.

Ch. Look again at the fish in the glass, and you will see, through the round part, two very large fish; and, seeing them from the upper part, they appear of their natural size. The deception is the same as with the shilling in the goblet.

Fa. The principle of refraction is productive of some very important effects. By this the sun, every clear morning, is seen several minutes before he comes to the horizon, and equally long after he sinks beneath it in the evening.

Ch. Then the days are longer than they would be if there were no such a thing as refraction. Will you explain how this happens?

Fa. I will. You know we have an atmosphere which extends all round the earth, and above it, to about the height of forty-five miles. Now, the dotted circles of fig. 5 represent that atmosphere. Suppose, then, a spectator to stand at *s*, and the sun to be at *b;* if there were no refraction, the person at *s* would not see the rays from the sun till he were situated, with regard to the sun, in a line *s x a;* because, when it was below the horizon at *b*, the rays would pass by the earth in the direction *b x o;* but, owing to the atmosphere, and its refracting power, when the rays from *b* reach *x*, they are bent towards the perpendicular, and carried to the spectator at *s*.

Ja. Will he really see the image of the sun while it is below the horizon?

Fa. He will: for it is easy to calculate the moment when the sun rises and sets; and if that be compared with exact observation, it will be found that the image of the sun is seen sooner and later than this, by several minutes, every clear day.

Ch. Are we subject to the same kind of deception when the sun is actually above the horizon?

Fa. We are always subject to it in these latitudes; and the sun is never actually in that place in the heavens where he appears to be.

Ja. Why in these latitudes particularly?

Fa. Because with us the sun is never in the *zenith*, *t*, or directly over our heads; and in that situation alone his *true* place in the heavens is the same as his *apparent* place.

Ch. Is that because there is no refraction when the rays fall perpendicularly on the atmosphere?

Fa. It is: but when the sun is at *m*, his rays will not proceed in a direct line, *m z o*, but will be bent out of their course at *o*, and pass in the direction *o s;* and the spectator will imagine that he sees the sun in the line *s o n*.

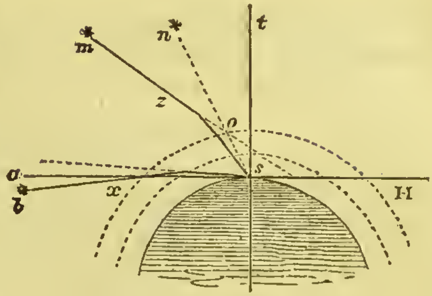


Fig. 5.

Ch. What makes the moon look so much larger when it is just above the horizon than when it is higher up?

Fa. The thickness of the atmosphere, when the moon is near the horizon, renders her less bright than when she is higher up; which leads us to suppose that she is farther off in the former case than in the latter; and, because we imagine her to be farther from us, we take her to be a larger object than when she is higher up.

It is owing to the atmosphere that the heavens appear bright in the daytime. Without an atmosphere that part only of the heavens would appear luminous in which the sun is placed: in that case, if we could live without air, and should stand with our backs to the sun, the whole heavens would appear as dark as night.

Reflection and *refraction* are terms derived from the Latin words *reflecto*, "I bend back;" and *refrango*, "I break back."

Ch. How long is it since the refractive power of the atmosphere was first observed?

Fa. The ancients, it appears, had some idea of it; but they had made no calculation of its quantity or of its action. Tycho Brahe was the first who settled its just quantity; but he attributed it to causes since found to be erroneous. Kepler was equally unsuccessful in his inquiries. It was not till after the invention of the barometer, which ascertained the regular decrease of density of the atmosphere upwards, that the refractive power of the atmosphere was proved to be exactly in proportion to its density. A ray of light, therefore, passing through the atmosphere, does not describe a straight line merely broken at one point, as is the case with any object partly immersed in water, but the refractive power increases at every point, and occasions the ray to describe a curve.

That branch of Optics peculiarly illustrative of *Refraction*

is called *Dioptrics*, from the Greek *dioptron* (διοπτρον), "something transparent," which is derived from *dia* (δια), "through," and *optomai* (ὀπτομαι), "I see."

QUESTIONS FOR EXAMINATION.

Show me how the principle of refraction will render a straight stick in water appear crooked? — How much higher does an object in water appear than it really is? — If a river or other clear water be six feet deep, how deep will it appear to a common observer? — Prove this by experiment. — Can you judge of magnitudes as well in water as in air? — Can you tell how the deception of the appearance of two pieces of money when there is but one can be explained? — What has the principle of refraction to do with regard to the sun? — Explain this by means of fig. 5. — Does the sun ever appear to be in that part of the heavens in which it is? — To the inhabitants of any part of the earth is the true and apparent place of the sun the same? — Why does the moon appear larger when it is near the horizon than when it is higher up in the heavens?

CONVERSATION V.

DEFINITIONS — OF THE DIFFERENT KINDS OF LENSES — OF MR. PARKER'S BURNING LENS, AND THE EFFECTS PRODUCED BY IT.

Father. I must now call your attention to a few other definitions; the knowledge of which you will require as we proceed.

"A PENCIL OF RAYS" is any number that proceed from a point.

"PARALLEL RAYS" are such as move in parallel lines, or those always at the same distance from each other.

Ch. That is something like the definition of "*parallel lines*" I have learnt from Euclid.* But when you admitted the rays of light through the small hole in the shutter, they did not seem to flow from that point in parallel lines, but to recede from each other in proportion to their distance from that point.

Fa. They did: and when they do thus recede from each other, as in this figure, from *e* to *cd*, then they are said to *diverge*. But if they continually approach towards each other, as in moving from *c d* to *e*, they are said to *converge*.

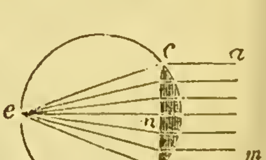


Fig. 6.

* Parallel lines are those which, being infinitely extended, never meet.

Ja. What does the dark part of this figure represent?

Fa. It represents a glass lens; of which there are several kinds.

Ch. What do you call a lens, Papa?

Fa. A *lens* is a piece of glass or other transparent substance made into such a form as to collect or disperse the rays of light which pass through it. Lenses take their names from their different shapes; and are represented here in one view.

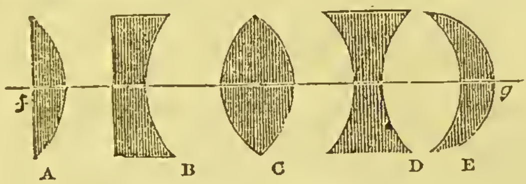


Fig. 7.

A is such a one as that in the last figure, and it is called a *plano-convex*, because one side is *flat*, or *plane*, and the other *convex*.

B is a *plano-concave*, one side being *flat* and the other *concave*.

C is a *double convex lens*, because both sides are convex.

D is a *double concave*, because both sides are concave.

E is called a *meniscus*, being convex on one side and concave on the other, and whose surfaces would meet if continued; of this latter kind are all watch-glasses.

A *concavo-convex* lens is that which has one of its surfaces *concave*, and the other *convex*, and which surfaces, if continued, would never meet.

Ja. I can easily imagine diverging rays, or rays proceeding from a point; but what is to make them converge, or come to a point?

Fa. Look again to the figure (fig. 6.) *a*, *b*, *m*, &c., represent parallel rays, falling upon a convex surface, of glass, for instance, all of which, except the middle one, fall upon it obliquely, and, according to what we saw yesterday, will be refracted towards the perpendicular.

Ch. And I see they will all meet in a certain point in that middle line.

Fa. That point, *e*, is called the *focus:* it is only the dark part of this figure that represents the glass as *c*, *d*, *n*.

Ch. Have you drawn the circle to show the exact curve of the different lens?

Fa. Yes: and you see that parallel rays falling upon a *plano-convex lens* (fig. 6.) meet at a point behind it; the distance of which from the middle of the glass is exactly equal to the diameter of the sphere of which the lens is a portion.

Ja. And in the case of a *double convex,* is the distance of the focus of parallel rays equal only to the radius of the sphere.

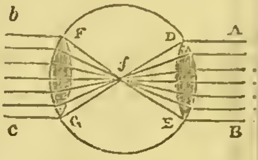


Fig. 8.

Fa. It is: and you see the reason of it immediately; for two concave surfaces have double the effect in refracting rays that a single one has; the *latter* bringing them to a focus at the distance of the diameter; the former at half that distance, which is the radius.

Ch. Sometimes, perhaps, the two sides of the same lens may have different curves. What is to be done then?

Fa. If you know the radius of both the curves, the following rule will give you the answer:

"As the sum of the radii of both curves or convexities is to the radius of either, so is double the radius of the other to the distance of the focus from the middle point."

Ja. Therefore, if one radius be four inches, and the other three inches, then, as $4+3 : 4 :: 6 : \frac{24}{7} = 3\frac{3}{7}$, or to nearly three inches and a half. I saw a gentleman lighting his cigar yesterday, by means of the sun's rays and a glass. Was that a double convex lens?

Fa. I suppose it was: and you now see the reason of what you then could not comprehend. All the rays of the sun that fall on the surface of the glass (see fig. 8.) are collected in the point *f*, which in this case may represent the top of the cigar.

The rays may be collected by reflection or refraction; by reflection, the rays fall on a concave looking-glass which is called a *mirror*, or on a concave reflector of brightly polished metal, which is called a *speculum:* the method we have just been describing is that by refraction.

Ch. How do you calculate the heat which is collected in the focus?

Fa. The force of the heat collected in the focus is, in proportion to the ordinary heat of the sun, as the area of the glass is to the area of the focal circle: of course it may be a hundred

or even a thousand times greater in the one case than in the other.

Ja. Have I not heard you say that a very large lens indeed was once used as a burning glass?

Fa. Yes; I have heard of one three feet in diameter, made of flint glass, and $3\frac{1}{4}$ inches thick; when fixed in its frame, it exposed a clear surface of more than two feet eight inches in diameter; its focal distance was six feet eight inches, and its weight 212lbs.; and its focus, by means of another lens, 13 inches in diameter, was reduced to a diameter of half an inch. The heat produced by this was so great, that iron plates were melted by it in three seconds; tiles and slates became red-hot in a moment, and were vitrified; sulphur, pitch, and other resinous bodies were melted under water; and ashes of wood and other vegetable substances were turned in a moment into transparent glass.

Ch. Would the heat produced by it melt all the metals?

Fa. It would: even gold was rendered fluid in a few seconds. Notwithstanding, however, this intense heat at the focus, the finger might, without the smallest injury, be placed in the cone of rays within an inch of the focus?

Ja. I suppose, however, that some danger would be incurred if the finger were brought too near the focus.

Fa. The curiosity of Mr. Parker, who was the ingenious maker of this burning-glass, led him to try what the sensation would be if he touched the focus: and he described it as similar to that produced by a sharp lancet, and not at all like the pain produced by the heat of fire or a candle. Substances of a white colour were not easily acted on. This glass of Mr. Parker's was carried to China by an officer in Lord Macartney's embassy, and left at Pekin.

Ch. I suppose he could make water boil in a very short time with the lens?

Fa. If the water be very clear, and contained in a clear glass decanter, the water will not be warmed by the most powerful lens; but a piece of wood contained in it may be burnt to a coal.

Ja. Will not the heat break the glass?

Fa. It will scarcely warm it. If, however, a piece of metal be put in the water, and the point of rays be thrown on

that, it will communicate heat to the water, and sometimes make it boil. The same effect will be produced if there be some ink thrown into the water.

If a cavity be made in a piece of charcoal, and the substance to be acted on be put in it, the effect produced by the lens will be much increased. Any metal thus inclosed melts in a moment; and the fire produced resembles that of a forge fiercely blown by the bellows.

I dare say you were at first surprised that such a small luminous spot as that described by the experiment should contain so much heat as to melt metals and cause water to boil; but having considered the principles on which it is produced, you will find that, in all cases, the degrees of heat collected by several glasses are, in proportion, compounded of their surfaces *directly*, and the squares of their focal distances reciprocally. The burning spot is the *spectrum* or picture of the sun, formed by a convex glass held parallel to its disk, which, by means of the several pencils, contracts all the rays that pass through it into that small compass.

Ch. Who invented the burning-glass?

Fa. It is not exactly known; the method, however, of thus producing heat is of great antiquity, for Archimedes is said to have burned the Roman fleet when in the harbour of Syracuse, by means of mirrors. The truth of this has been doubted; but yet we read of Buffon, in the middle of the eighteenth century, setting fire to planks of wood, 150 feet distant, by means of 168 mirrors, each about six inches square.

QUESTIONS FOR EXAMINATION.

What do you mean by a pencil of rays? — What are parallel rays? — What is meant by diverging and converging rays? — What is a lens? — How many kinds of lenses are there, and what are their names? — What is the focus? — Where do parallel rays falling upon a plano-convex lens meet? — Where do they meet in a double convex? — What is the reason of it? — — Can you tell me the rule for finding the focus if the two sides of a double convex are of different curves? — What is the principle of the burning-glass? — Do you know how to calculate the force of the heat collected in the focus of a burning-glass? — What was the size of Mr. Parker's lens? — What effects were produced by it? — Are white substances and water easily affected by the lens.

CONVERSATION VI.

OF PARALLEL, DIVERGING, AND CONVERGING RAYS—OF THE FOCUS AND FOCAL DISTANCES.

Charles. I have been looking at the figures 6 and 8, and see that the rays falling upon the lenses are parallel to one another. Are the sun's rays parallel?

Fa. They are considered so: but you must not suppose that all the rays which come to the eye from the surface of an object, such as the sun or any other body, are parallel to each other; but it must be understood of those rays only which proceed from a single point. Suppose S to be the sun; the rays which proceed from a single point, A, do in reality form a cone; the *base* of which is the pupil of the eye, and its height is the distance from us to the sun.

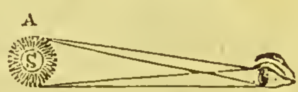


Fig. 9.

Ja. But the breadth of the eye is nothing when compared to a line ninety-five millions of miles long.

Fa. And for that reason the various rays that proceed from a single point in the sun are considered as parallel, because their inclination to each other is insensible. The same may be said of any other point, as C. Now, all the rays that we can admit by means of a small aperture or hole, must proceed from an indefinitely small point of the sun; and therefore they are justly considered as parallel.

If, now, we take a ray from the point A, and another from C, on opposite points of the sun's disk, they will form a sensible angle at the eye; and it is from this angle, A E C, that we judge of the apparent size of the sun, which is about half a degree in diameter.

Ch. Will the size of the pupil of the eye make any difference with regard to the appearance of the object?

Fa. The larger the pupil, the brighter will the object appear; because in proportion to the size will be the number of rays it will receive from any single point of the object. I wish you also to remember what I have told you before, that, whenever the appearance of a given object is rendered larger

and brighter, we always imagine that the object is nearer to us than it really is, or than it appears to be at other times.

Ja. If there be nothing to receive the rays (fig. 8) at *f*, would they cross one another and diverge?

Fa. Certainly; in the same manner as they converged in coming to it; and if another glass, F G, of the same convexity as D E, be placed in the rays at the same distance from the focus, it will so refract them, that, after going out of it, they will be parallel, and so proceed in the same manner as they came to the first glass.

Ch. There is, however, this difference: that all the rays, except the middle one, have changed sides.

Fa. You are right: the ray B, which entered at bottom, goes out at the top *b*; and A, which entered at the top, goes out at the bottom *c*; and so of the rest.

If a candle be placed at *f*, the focus of the convex glass, the diverging rays in the space *f* F G, will be so refracted by the glass, that, after going out of it, they will become parallel again.

Ja. What will be the effect if the candle be nearer to the glass than the point *f*?

Fa. In that case, if the candle be at *g* the rays will diverge after they have passed through the glass, and the divergency will be more or less in proportion to the distance of the candle from the focus.

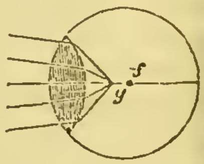


Fig. 10.

Ch. If the candle be placed farther from the lens than the focus *f*, will the rays meet in a point, after they have passed through it?

Fa. They will. Thus, if the candle be placed at *g* the rays, after passing the lens, will meet in *x*; and this point, *x*, will be *more* or less distant from the glass, as the candle is *nearer* to, or farther from its focus. Where the rays meet they form an *inverted* image of the flame of the candle.

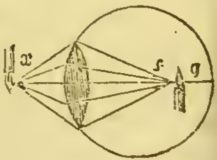


Fig. 11.

Ja. Why so?

Fa. Because that is the point where the rays, if they are not stopped, cross each other. To satisfy you on this head I will hold in that point a sheet of paper; and you now see that the flame of the candle is inverted.

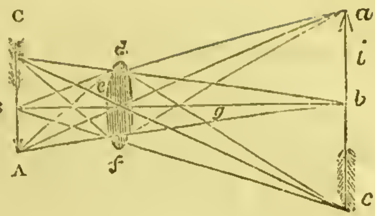


Fig. 12.

This may be explained in the following manner: let *a b c* represent an arrow placed beyond the focus *g* of a double convex lens, *d e f*, some rays will flow from every part of the arrow, and fall on the lens: but we shall consider only those which flow from the points *a*, *b*, and *c*. The rays which come from *a*, as *a d*, *a e*, and *a f*, will be refracted by the lens, and meet in A; those which come from *b*, as *b d*, *b e*, and *b f*, will unite in B; and those which come from *c* will unite in C.

Ch. I see clearly how the rays from *b* are refracted, and unite in B; but it is not so evident with regard to those from the extremities *a* and *c*.

Fa. I admit it: but you must remember the difficulty consists in this: the rays fall more obliquely on the glass from those points than from the middle; and therefore the refraction is very different. The ray, *b g*, in the centre, suffers no refraction; *b d* is refracted into B; and if another ray went from *i*, as *i d*, it would be refracted to I somewhere between B and A, and the rays from *a* must, for the same reason, be refracted to A.

Ja. If the object, *a b c*, be brought nearer to the glass, will the picture be removed to a greater distance?

Fa. It will: for then the rays will fall more divergingly upon the glass, and cannot be so soon collected into the corresponding points behind it.

Ch. From what you have said, I understand that if the object, *a b c*, be placed in *g*, the rays, after refraction, will go out parallel to one another; and if brought nearer to the glass than *g*, then they will diverge from one another; so that, in neither case, an image will be formed behind the lens.

Ja. To form an image, must the object be beyond the focus *g*?

Fa. It must: and the picture will be larger or smaller than the object, as its distance from the glass is greater or less than the distance of the object: if *a b c* (fig. 12) be the object, C B A will be the picture; and if C B A be the object, *a b c* will be the picture.

Ch. Is there any rule to find the distance of the picture from the glass?

Fa. If you know the focal distance of the glass, and the distance of the object from the glass, the rule is this:

"Multiply the distance of the focus by the distanec of the objeet, and divide the product by their differencc; the quotient is the distance of the picture."

Ja. If the foeal distance of the glass be 7 inches, and the objeet be 9 inches from the lens, then $\frac{7 \times 9}{2} = \frac{63}{2} = 31\frac{1}{2}$ inches: of course, the picture will be very much larger than the object: for, as you have said, the picture is as much larger or smaller than the object, as its distance from the glass is greater or less than the distance of the object.

Fa. If the focus be seven inches, and the object at the distance of 17 inches, then the distanee of the picture will be found thus $\frac{7 \times 17}{10} = \frac{119}{10} = 12$ inehcs nearly.

QUESTIONS FOR EXAMINATION.

Doos the magnitude of the pupil of the eye make any difference with regard to the appearance of the object?—What effect does the magnitude and lightness of an object produce?—As the rays passing through a double convex lens meet in the focus, what will happen if there is nothing to receive them there?—What effect will be produced if a candle is placed in the focus of a double convex lens?—What will be the effect if it be put nearer or farther from the lens than the focus?—What is the cause of an inverted image?—Can you explain this by fig. 12?—What is the rule for finding the distance of the picture from the glass?

CONVERSATION VII.

IMAGES OF OBJECTS INVERTED—OF THE SCIOPTRIC BALL—OF LENSES AND THEIR FOCI.

James. Will the image of a candle, when received through a convex lens, be inverted?

Fa. It will, as you shall see. Here is no light in this room but from the candle, the rays of which pass through a convex lens; and, by holding a sheet of paper in a proper position, you will see a eomplete inverted image of the candle on it.

An object seen through a very small aperture appears also inverted, but it is very imperfect compared with an

image formed with the lens: it is *faint* for want of light; and it is *confused* because the rays interfere with one another.

Ch. What is the reason of its being inverted?

Fa. Because the rays from the extreme parts of the object must cross at the hole. If you look through a very small hole at any object, the object appears magnified. Make a pin-hole in a sheet of brown paper, and look through it at the small print of this book.

Ja. It is, indeed, very much magnified.

Fa. As an object approaches a convex lens, its image departs from it; and as the object recedes, its image advances. Make the experiment with a candle and a lens, properly mounted in a long room: when you stand at one end of the room, and throw the image on the opposite wall, the image is large, but as you come nearer the wall, the image is small. and the distance between the candle and glass is very much increased.

I will now show you an instrument, called a "*Scioptric Ball*," which is fastened into a window-shutter in a room from which all light is excluded except what comes in through this glass.

Ch. Of what does this instrument consist? and what a curious appellation you have given it.

Fa. It consists of a frame, A B, and a ball of wood, C, in which is a glass lens; and it is so adjusted that the ball moves easily in the frame in all directions; that the view of any surrounding object may be received through it: it derives its name from two Greek words, *scia* (σκια), "a shadow," and *optomai* (οπτομαι), "I view."

Fig. 13.

Ja. Do you screw this frame into the shutter?

Fa. Yes; a hole is cut in it for that purpose; and there are little brass screws belonging to it, such as that marked *s*. When it is fixed in its place, a screen must be placed at a proper distance from the lens, to receive images of the objects out of doors. This instrument is sometimes called an Artificial Eye.

Ch. In what respects is it like the eye?

Fa. The frame has been compared to the socket in which the eye moves, and the wooden ball to the whole globe of the eye; the hole in the ball represents the pupil; the convex

lens corresponds to the crystalline humour; and the screen may be compared with the retina. These terms I will explain to you by and bye.

Ja. The ball, by turning in all directions, is very like the eye; for, without moving my head, I can look on all sides, and upwards and downwards.

Fa. Well: we will now place the screen properly, and turn the ball to the garden. Here you see all the objects perfectly represented.

Ja. But they are all inverted.

Fa. That is the great defect of this instrument; but I will tell you how it may be remedied. Take a looking-glass, and hold it before you with its face towards the picture on the screen, and inclining a little downwards, and the images will appear erect in the glass, and even brighter than they were on the screen.

Ch. You have shown us in what manner the rays of light are refracted by convex lenses when those rays are parallel. Will there not be a difference if the rays *converge* or *diverge* before they enter the lens?

Fa. Certainly: if rays *converge* before they enter a convex lens, they will be collected at a point *nearer* to the lens than the focus of parallel rays: but if they *diverge* before they enter the lens, they will then be collected in a point *beyond* the focus of parallel rays.

There are concave as well as convex lenses; and the refraction which takes place by means of these differs from that which I have already explained.

Ch. What will the effect of refraction be when parallel rays fall upon a double concave lens?

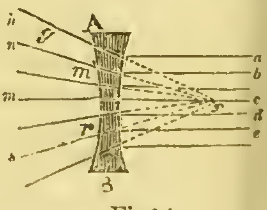


Fig 14.

Fa. Suppose the parallel rays *a*, *b*, *c*, *d*, &c., pass through the lens A B, they will *diverge* after they have passed through the glass.

Ja. Is there any rule for ascertaining the degree of divergency?

Fa. Yes; it will be precisely so much as if the rays had come from a radiant point, x, which is the centre of the concavity of the glass.

Ch. Is that point called the focus?

Fa. It is called the *virtual* or *imaginary focus.* Thus the

ray *a*, after passing through the glass A B, will go on in the direction *g h*, as if it had come from the point *x*, and no glass had been in the way; the ray *b* would proceed in the direction *m n*, and the ray *e* in the direction *r s*, and so on. The ray *c x*, in the centre, suffers no refraction, but proceeds precisely as if no glass had been in the way.

Ja. Suppose the lens had been concave on one side only and the other side had been flat: how would the rays have diverged?

Fa. They would have diverged, after passing through it, as if they had come from a radiant point at the distance of a whole diameter of the convexity of the lens.

Ch. There is, consequently, a great similarity in the refraction of the convex and concave lens.

Fa. Yes; the *focus* of a double convex lens is at the distance of the radius of convexity, and so is the *imaginary focus* of the double concave; and the *focus* of the plano-convex is at the distance of the diameter of the convexity, and so is the *imaginary focus* of the plano-concave.

You will find that images formed by a concave lens, or those formed by a convex lens, where the object is *within* its principal focus, are in the same position with the objects they represent: they are also *imaginary;* for the refracted rays never meet at the foci whence they seem to diverge.

But the images of objects placed beyond the focus of a convex lens are inverted, and *real;* for the refracted rays meet at their proper foci.

QUESTIONS FOR EXAMINATION.

How is it known that the image of a candle when received through a convex lens will be inverted? — What is the appearance of an object seen through a very small aperture, and what is the reason of it? — By looking at a small print through a pin hole in brown paper, what is the effect produced? — What is the scioptric ball, and what does it represent? — How is it compared to the eye? — What is the chief defect in the scioptric ball? — How is that remedied? — What is the virtual or imaginary focus? — Is there any similarity in the refraction of the convex and concave lens?

CONVERSATION VIII.

OF THE NATURE AND ADVANTAGES OF LIGHT — OF THE SEPARATION OF THE RAYS OF LIGHT BY MEANS OF A PRISM — AND OF COMPOUND RAYS, &c.

Father. We cannot contemplate the nature of light without being struck with the great advantages which we enjoy from it. Without that blessing our condition would be truly deplorable.

Ja. But you have told us that the light would be of comparatively small advantage without an atmosphere.

Fa. The atmosphere not only *refracts* the rays of light, so that we enjoy longer days than we should without it, but occasions that twilight, which is so beneficial to our eyes; for without it the appearance and disappearance of the sun would have been instantaneous; and in every twenty-four hours we should have experienced a sudden transition from the brightest sunshine to the most profound darkness, and from thick darkness to a blaze of light.

Ch. I know how painful that would be, from having slept in a very dark room, and having suddenly opened the shutters when the sun was shining extremely bright.

Fa. The atmosphere reflects also the light in every direction; and if there were no atmosphere, the sun would benefit those only who looked towards it; and to those whose backs were turned to that luminary, it would all be darkness.

Ja. I saw, in some of your experiments, that the rays of light, after passing through the glass, were tinged with different colours. What is the reason of that?

Fa. Formerly, light was supposed to be a simple and uncompounded body. Sir Isaac Newton, however, discovered that it was not a simple substance, but composed of several parts; each of which has, in fact, a different degree of refrangibility, or disposition to be turned out of its natural course, by passing out of one medium into another.

Ch. How is that to be observed?

Fa. Let the room be darkened; and only a very small hole open in the shutter to admit the sun's rays: Instead of a lens, I will take a triangular piece of glass, called a *prism:* now, as in this there is nothing to bring the rays to a focus, they will,

in passing through it, suffer different degrees of refraction, and be separated into the different coloured rays, which, if received on a sheet of white paper, will exhibit the seven following colours: *red, orange, yellow, green, blue, indigo*, and *violet.*

Ja. Here are all the colours of the rainbow! but the image on the paper is a sort of oblong.

Fa. That oblong image is usually called a *spectrum;* and if it be divided into 360 equal parts, the red will occupy 45 of them, the orange 27, the yellow 48, the green and the blue 60 each, the indigo 40, and the violet 80. This experiment effects what is called the decomposition of light.

Ch. The shade of difference in some of these colours seems very small indeed.

Fa. You are not the only person who has made this observation. Some experimental philosophers say that there are but three original and truly distinct colours—viz., the *red, yellow,* and *blue.*

Ch. What is called the *orange* is surely only a mixture of the red and yellow, between which it is situated.

Fa. In like manner the green is said to be a mixture of the yellow and blue; and the violet is but a fainter tinge of the indigo.

Ja. How is it, then, that light, which consists of several colours, is usually seen as white?

Fa. By mixing the several colours in due proportion, white may be produced.

Ja. Do you mean to say that a mixture of red, orange, yellow, green, blue, indigo, and violet, in any proportion, will produce a white?

Fa. If you divide a circular surface into 360 parts, and then paint it in the proportion just mentioned (that is, 45 of the parts red, 27 orange, 48 yellow, &c.) and turn it round with great velocity, the whole will appear of a dirty white; and if the colours were more perfect, the white would be more completely so.

Ja. Was it, then, owing to the separation of the different rays that I saw the rainbow colours about the edges of the image made with the lens?

Fa. It was. Some of the rays were scattered, and not brought to a focus; and these were divided in the course of refraction. And I may tell you now, though I shall not ex-

plain it at present, that the rainbow is caused by the separation of the rays of light into their component parts.

Ja. What colour is most reflected by the air?

Fa. Blue, and therefore it absorbs the red, orange, and yellow more copiously than the other rays.

Ja. Is black a colour?

Fa. Not properly. It is black because it does not reflect but absorbs all rays of light that fall upon it. Black hats are not so comfortable as white ones in hot climates, because the heat which accompanies the sun's luminous rays is also absorbed by the black surface.

Ja. Why are white hats, or clothing, preferable in hot climates?

Fa. Because white reflects the light.

QUESTIONS FOR EXAMINATION.

Of what advantage is the atmosphere as it respects light?—Would not the sudden transitions from light to darkness, and the reverse, be very inconvenient?—How should we be benefited by the sun if there were no atmosphere?—Is light a simple or a compound substance?—Into how many colours can a ray of light be divided?—What is the oblong spectrum on which the colours are painted called?—Have all philosophers admitted of seven colours in the rays of light?—Can white be produced by mixing the other colours?—In what manner is that done?—How is the rainbow caused?

CONVERSATION IX.

OF COLOURS.

Charles. I am now anxious to know the cause of different colours. The cloth on this table is green; and that of which my coat is made is blue. What makes the difference in these?

Fa. I explained to you that white, or ordinary light, was composed of several colours, and that when these entered the eye, in proper proportion, the sensation or impression produced was white; but if any of these coloured rays are absorbed or checked by any surface, the remainder continue their course, and appear of that colour which arises from the mixture of the unchecked rays. You will also recollect I told you that, according to the undulatory theory, light consisted of the particles of an ether in a state of undulatory or wavy motion. Hence, if the undulations of which some of the colours are composed should interfere with or check each other, these would be no longer apparent, and only those would reach the eye which continue their course. I shall give you an illustration of this presently.

Ja. Is it from the reflected rays that we judge of the colour of objects?

Fa. It has generally been thought so. Thus the cloth on the table absorbs all the rays but the green, which it reflects to the eye; but your coat is of a different nature, as to its colour, and absorbs all but the blue rays.

Ch. Why are paper and snow white?

Fa. The whiteness of paper is occasioned by its reflecting the greatest part of all the rays that fall upon it; and every flake of snow, being an assemblage of frozen particles of water, reflects and refracts the rays of light that fall upon it in all directions, so as to mix them very intimately, and produce a white impression on the eye.

Ja. Does the whiteness of the sun's light arise from a mixture of all the primary colours?

Fa. It does; as may be easily proved by an experiment: for, if any of the seven colours be intercepted at the lens, the image in a great measure loses its whiteness. With the prism I will divide a ray into its seven colours:* I will then take a convex lens, in order to re-unite them into a single ray, which will exhibit a round image of a shining white; but if only a few of these rays be taken with the lens, it will produce a dusky white.

Ja. The diamond, I have heard, owes its brilliancy to the power of reflecting almost all the rays of light that fall on it: but are vegetable and animal substances equally indebted to light?

Fa. What does the gardener do to make his endive and lettuces white?

Ch. He ties them up.

Fa. That is, he shuts out the light; and by this method they become blanched. I could produce you a thousand instances to show, not only that the colour, but even the existence, of vegetables depends upon light. Close-wooded trees have only leaves on the outside: such is the cedar in the garden. Look at a yew tree, and you will find that the inner branches are almost, or altogether, barren of leaves. Geraniums, and other green-house plants, turn their flowers to the light; and plants in general, if doomed to darkness, soon sicken and die.

* Further information on this subject is given in Conversation XVIII., on the Rainbow.

Ja. There are some flowers, the petals of which are, in different parts, of different colours: how do you account for this?

Fa. The flowers of the heart's-ease, and of the tulip, are of this kind; and if examined with a good microscope, it will be found that the *texture* of the blue and yellow parts is very different. The texture of the leaves of the white and red rose is also different. Clouds also, which are so various in their colours, are undoubtedly more or less dense, as well as being differently placed with regard to the eye of the spectator; but the whole depend on the light of the sun for their beauty.

Ch. Are we to understand that all colours depend on the reflection of the several coloured rays of light?

Fa. This seems to have been the opinion of Sir Isaac Newton; but he concluded, from various experiments on the subject, that every substance in nature, provided it be reduced to a proper degree of thinness, is transparent. Many transparent *media* reflect one colour and transmit another: gold-leaf reflects the yellow, but it transmits a sort of green colour when held up against a strong light.

Ch. Of what colour is the light of the sun?

Fa. It consists of rays of different kinds. Those which partake of the same degree of refrangibility are called *homogeneal*, and those which have different degrees of refrangibility are called *heterogeneal.* Each ray exhibits its proper colour according to its refrangibility, which cannot be changed either by reflection or refraction. A collection of all the colours, gathered by means of a lens, as we have seen, will be perfectly white.

Ch. How is it the colours appear in the bubble produced by a solution of soap in water, blown through a tobacco-pipe?

Fa. If the bubble, as soon as blown, be not covered with a glass, it will be too much agitated by the external air to allow of any regular observation: but this precaution being taken, the colours will be seen to emerge from the vertex or top of the bubble; and as it grows thinner, by the subsidence of the water, they dilate into circles or rings, parallel to the horizon, and then slowly descend and vanish successively at the bottom. This continues till the water of the vertex becomes too thin

to reflect the light, when a circular spot of intense blackness appears at the top, which slowly dilates, sometimes to three quarters of an inch in breadth, before the bubble bursts. From the black central spot the reflected colours are the same in succession and nature as those produced by a plate of air; and the appearance of the bubble, if viewed by transmitted light, is also similar to that of the plate of air in like circumstances.

Ch. What is meant by a plate of air?

Fa. If a glass or lens, the surface of which is convex, or part of a sphere, be laid upon a plane glass, it will of course touch at one point only; and therefore at all other places between the adjacent surfaces will be interposed a thin layer or plate of air, the thickness of which will increase in a certain ratio according to the distance from the point of contact. Light, therefore, incident upon such a plate of air, is disposed to be transmitted or reflected, according to its thickness.

QUESTIONS FOR EXAMINATION.

What description can you give of colours? — How are colours supposed to exist? — By what do we judge of the colour of objects? — How do you account for the whiteness of paper or snow? — From what does the whiteness of the sun's light arise? — How is that proved? — To what are we indebted for all the fine colours exhibited in nature? — Are the vegetable and animal kingdoms indebted to the light for their various colours? — What is the theory of blanching lettuces, cabbages, &c.? — What makes the different parts of the same flower, as the heart's-ease, of different colours? — Do all colours depend on the reflection of the several coloured rays of light? — Do some transparent media reflect one colour and transmit another?

CONVERSATION X.

REFLECTED LIGHT, AND PLANE MIRRORS.

Father. We come now to treat of a different kind of glasses, —viz., *mirrors*, or, as they are sometimes called, *specula*.

Ja. Is not a looking-glass termed a mirror?

Fa. Mirrors are made of glass, silvered on one side, or of highly-polished metal. They are of three kinds; the *plane*, the *convex*, and the *concave*.

Ch. You have shown us that in a looking-glass or plan mirror, "The angle of reflection is always equal to the angl of incidence."

Fa. This rule is not only applicable to plane mirrors, bu to those which are convex and concave also, as I shall shov you to-morrow. But I wish to make some observations firs on plane mirrors. In the first place, if you wish to see th complete image of yourself in a plane mirror or looking-glass it must be *half* as long as you are high.

Ja. I should have imagined the glass must have been a long as I am high.

Fa. In looking at your image in the glass, does it not seen to be as far behind the glass as you stand before it?

Ja. Yes: and if I move forwards or backwards, the imag behind the glass seems to approach or recede.

Fa. Let $a\ b$ be the looking-glass, and A the spectator, standing opposite to it. The ray from his eye will be reflected in the same line A a, but the ray $c b$, flowing from his foot, in order to be seen at the eye must be reflected by the line b A.

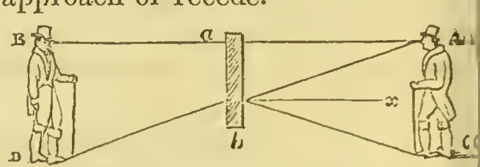


Fig. 15.

Ch. So it will: for if xb be a line perpendicular to the glass, the incident angle will be cbx, equal to the reflected angle Abx.

Fa. And therefore the foot will appear behind the glass at D along the line AbD; because that is the line in which the ray last approaches the eye.

Ja. Is that part of the glass, ab, intercepted by the lines AB and AD, equal exactly to half the length BD, or Ac?

Fa. It is: Aab and ABD may be supposed to form two triangles, the sides of which always bear a fixed proportion to one another; and if AB is double of Aa, as in this case it is, BD will be double of ab, or at least of that part of the glass intercepted by AB and AD.

Ch. This will hold true, I see, at whatever distance we may stand from the glass.

Fa. If you walk towards a looking-glass, your image will approach with double velocity; because the two motions are equal and contrary: but if, while you stand before a looking-

glass, your brother walk up to you from behind, his image will appear to you to move at the same rate as he walks; although to him the velocity of the image will appear to be double; for, with regard to you, there will be but one motion, but, with regard to him, there will be two equal and contrary ones.

Ja. If I look at the reflection of a candle in a looking-glass, I see in fact two images: one much fainter than the other. What is the reason of this?

Fa. Any object strongly illuminated will appear in the same manner. The cause of the double image is, that a part of the rays which form the faint image, are immediately reflected from the upper surface of the glass, while the greater part of them are reflected from the further surface, or silvered part, and form the vivid image. To see these two images you must stand a little sideways, and not directly before the glass.

Ch. What is meant by the expression of " an image being formed behind a reflector?"

Fa. It is intended to denote that the reflected rays come to the eye with the same inclination as if the object itself were actually behind the reflector. If you, standing on one side of the room, see the image of your brother, who is on the other side, in the looking-glass, the image will seem to be formed behind the glass; that is, the rays come to your eye precisely in the same way as they would if your brother himself stood in that place, without the intervention of a glass.

Ja. But the image in the glass is not so bright or vivid as the object.

Fa. A plane mirror is, in theory, supposed to reflect all the light which falls upon it; but in practice, nearly half the light is lost on account of the inaccuracy of the polish, &c. Polished metallic specula are of as great antiquity as mirrors, having been used by the Egyptians and Jews also.

Ch. Did you not say that Archimedes, at the siege of Syracuse, burnt the ships of Marcellus by a machine composed of mirrors?

Fa. Yes; these were concave mirrors: but we have no certain accounts that may be implicitly relied on. M. Buffon, many years ago, burnt a plank, at the distance of several feet, which I have already related to you.

Ja. I do not see how these mirrors can act as burning-glasses?

Fa. A plane mirror reflects the light and heat proceeding from the sun, and will illuminate and heat any substance on which they are thrown, in the same manner as if the sun shone upon it. Two mirrors will reflect on it a double quantity of heat; and if 40 or 100 mirrors could be so placed that each of them may reflect the heat coming from the sun, on any particular substance, they would increase the heat 40 or 100 times.

Ch. Why is the truth of the burning of the Roman ships before Syracuse, by Archimedes, a question of doubt?

Fa. One reason is, perhaps, that if he did effect that object, the vessels must have been aground, and very near to the walls of the besieged city, respecting which there may be some doubt: for if they were at anchor, the undulations of the sea, even in the finest weather, must have so varied the focus, or burning point, as to defeat his intention. Had the object been fixed, and at no very great distance, it might have been accomplished.

Ch. What is the rule for calculating the powers of burning-glasses, as they are termed?

Fa. If a lens, four inches broad, collect the sun's rays into a focus, at the distance of one foot, the image will not be more than a tenth part of an inch broad. The surface of this little focal circle, therefore, will be one thousand six hundred times less than the surface of the lens; and, consequently, the sun's light must be so many times denser within that circle.

QUESTIONS FOR EXAMINATION.

Of what are mirrors made? — How many kinds of mirrors are there? — What is the general rule with regard to the angle of reflection? — Is this rule applicable to mirrors of all kinds? — Of what length must a looking-glass be for a person to see his complete image? —In looking at your image in the glass, how much behind the glass does it appear to stand? — Can you explain for what fig. 15 is intended? — What is the appearance if you walk towards a looking-glass? — What is the reason of the double image in the looking-glass? — How do you explain the expression "An image formed behind a reflector?" — How much light does a plane mirror reflect? — Have not mirrors been applied as burning-glasses?

CONVERSATION XI.

OF CONCAVE MIRRORS—THEIR USES—AND MODE OF ACTION.

James. To what uses are concave mirrors applied?

Fa. They are chiefly used in reflecting telescopes; that is, in telescopes adapted to viewing the heavenly bodies: and as you like to look at Jupiter's moons and Saturn's ring through my telescope, it may be worth your while to take some pains to know by what means this pleasure is afforded you.

Ch. I shall not object to give any attention necessary to comprehend how these instruments are contrived.

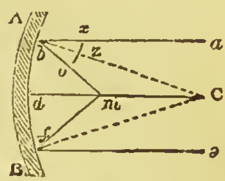


Fig. 16.

Fa. A B represents a concave mirror, and *a b*, c *d*, *e f*, three parallel rays of light falling upon it:—c is the centre of concavity; that is, one leg of your compasses being placed on c, and the other opened to the length c *d*, the latter will touch the mirror A B in all its parts.

Ja. Then all the lines drawn from c to the glass will be equal to one another, as c *b*, c *d*, and c *f*.

Fa. They will: and there is another property belonging to them; which is, that they are all perpendicular to the glass in the parts where they touch.

Ch. That is, c *b*, and c *f* are perpendicular to the glass at *b* and *f*, as well as c *d* at *d*.

Fa. Yes:—c *d* is an *incident* ray, but, as it passes through the centre of concavity, it will be reflected back in the same line; that is, as it makes no angle of incidence, so there will be no angle of reflection: *a b* is an *incident* ray; and I want to know what will be the direction of the reflected ray?

Ch. Since c *b* is perpendicular to the glass at *b*, the angle of incidence is *a b* c; and as the angle of reflection is always equal to the angle of incidence, I must make another angle, as c *b m* equal to *a b* c,* and then the line *b m* is that in which the incident ray will move after reflection.

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* To make an angle c *b m*, equal to another given one, as *a b* c: from *b* as a centre with any radius *b x*, describe the arc *x o*, which will cut c *b* in *z*, take the distance *x z* in your compasses, and set off with it *z o*, and then draw the line *b o m*, and the angle *m b* c is equal to the angle *a b* c.

Fa. Can you, James, tell me how to find the line in which the incident ray *ef* will move after reflection?

Ja. Yes: I will make the angle c*fm* equal to c*fe*, and the line *fm* will be that in which the reflected ray will move; therefore *ef* is reflected to the same point *m* as *ab* was.

Fa. If, instead of two incident rays, any number were drawn parallel to c*d*, they would every one be reflected to the same point, *m;* and that point, which is called the *focus of parallel rays*, is distant from the mirror half the radius c*d.*

Ja. Then we may easily find the point without the trouble of drawing the angles, merely by dividing the radius of concavity into two equal parts.

Fa. You may. We have already observed that the rays which proceed from any point of a celestial object may be esteemed parallel at the earth; and therefore the image of that point will be formed at *m.*

Ch. Do you mean that all the rays flowing from the point of a star, and falling upon such a mirror, will be reflected to the point *m*, where the image of the star will appear?

Fa. I do; and if there be any body placed at the point *m* to receive the image, this will be evident to you.

Ja. Will not the same rule hold good with regard to terrestrial objects?

Fa. No: for the rays which proceed from any terrestrial object, however remote, cannot be esteemed strictly parallel; they therefore *diverge*, and will not be converged to a *single point* at the distance of half the radius of the mirror from the reflecting surface; but in *separate points* at a somewhat greater distance from the mirror than half the radius.

Ch. Can you explain this by a figure?

Fa. I will endeavour to do so. Let A B be a concave mirror, and M E any remote object, from every part of which rays will proceed to every point of the mirror; that is, from the point M rays will flow to every point of the mirror; and so they will from E, and from every point between these extremities. Let us see where the rays that proceed from M to A, *c* and B will be reflected, or, in other words, where the image of the point M will be formed.

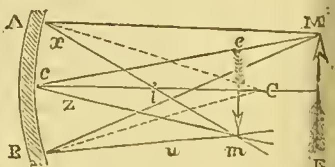


Fig. 17.

Ja. Will all the rays that proceed from M, to different parts of the glass, be reflected to a single point?

Fa. Yes: and the difficulty is to find that point. I will take only three rays, to prevent confusion,—viz., M A, M *c*, M B; and C is the centre of concavity of the glass.

Ch. Then, if I draw C A, that line will be perpendicular to the glass at the point A; the angle M A C is now given; and it is the angle of incidence.

Ja. And you must make another equal to it as you did before.

Fa. Certainly: make C A *x* equal to M A C, and extend the line A *x* to any length you please.

Now you have an angle M *c* C, made with the ray M *c* and the perpendicular C *c*, which is another angle of incidence.

Ch. I will make the angle of reflection C *c z* equal to it, and the line *c z*, being produced, cuts the line A *x* in a particular point, which I will call *m*.

Fa. Draw now the perpendicular C B, and you have with it, and the ray M B, the angle of incidence M B C. Make another angle equal to it, as its angle of reflection.

Ja. The angle C B *u* will be that angle; and I find that the line B *u* meets the other lines at the point *m*.

Fa. Then *m* is the point in which all the reflected rays of M will converge: of course the image of the extremity, M, of the arrow E M will be formed at *m*. Now, the same might be shown of every other part of the object M E, the image of which will be represented by *e m*, which you see is at a greater distance from the glass than half C *c*, or its radius.

Ch. The image, I perceive, is *inverted* also, and *less* than the object, which I suppose is usually the case in such circumstances.

QUESTIONS FOR EXAMINATION.

What are concave mirrors used for? —Do you know how to find the focus of parallel rays of a concave mirror?—Are all the rays that proceed from a celestial object to be deemed parallel? —Does the same hold with regard to terrestrial objects? — Is the image formed by a concave mirror erect or inverted?

CONVERSATION XII.

OF CONCAVE MIRRORS, AND EXPERIMENTS ON THEM.

Father. If you well understand what we conversed on yesterday, you will easily see how the image is formed by the large concave mirror of the reflecting telescope, when we come to examine the construction of that instrument.—In a concave mirror, the image is *less* than the object, when the object is more remote from the mirror than C, the centre of concavity; and in that case the image is between the object and the mirror.

Ja. Suppose the object to be placed in the *centre*, C.

Fa. Then the image and object will coincide: and if the object be placed nearer to the glass than the centre, C, then the image will be more remote, and larger than the object.

Ch. I should like to see this illustrated by an experiment.

Fa. Well; here is a large concave mirror. Place yourself before it, beyond the centre of the concavity, and, with a little care in adjusting your position, you will see an inverted image of yourself in the air, between you and the mirror, and of a more diminutive size than yourself. When you see the image, extend your hand gently towards the glass, and the hand of the image will advance to meet it till they both come in contact with the centre of the concavity of the glass. If you carry your hand still further, the hand of the image will pass by it, and come between it and the body. Now move your hand to either side, and the image of it will move towards the other.

Ja. Is there any rule for finding the distance at which the image of an object is formed from the mirror?

Fa. If you know the radius of the concavity of the mirror, and also the distance of the object from the glass, "multiply the distance and radius together, and divide the product by double the distance, less the radius, and the quotient is the distance required."

Tell me at what distance the image of an object will be, if the radius of the concavity of the mirror be 12 inches and the object be 18 inches from it.

Ja. I must multiply 18 by 12, which is equal to 216: this I divide by twice 18, or 36, less by 12; that is 24; but 216

divided by 24 gives 9, which is the number of inches required.

Fa. You may vary this example in order to impress the rule on your memory; and I will show you another experiment. Take this bottle, partly full of water, and cork it. I place it opposite the concave mirror, and beyond the focus, that it may appear to be reversed. Now stand a little further distant than the bottle, and you will see the bottle inverted in the air, and the water which is in the lower part of the bottle will appear to be in the upper part. I will invert the bottle, and uncork it; and whilst the water is running out the image will appear to be filling; when the bottle is empty, however, the illusion is at an end.

Ch. Are concave mirrors ever used as burning-glasses?

Fa. Since it is the property of these mirrors to cause parallel rays to converge to a focus, and since the rays of the sun are considered as parallel, they are very useful as burning-glasses; and the principal focus is the burning point.

Ja. Is the image formed by a concave mirror always before it?

Fa. In all cases, except when the object is nearer to the mirror than the principal focus.

Ch. Is the image, then, behind the mirror?

Fa. It is: and further behind the mirror than the object is before it. Let A C be a mirror, and *x z* the object between the centre, K, of the glass and the glass itself; and the image X Y Z will be behind the glass, erect. curved, and magnified, and of course the image is further behind the glass than the object is before it.

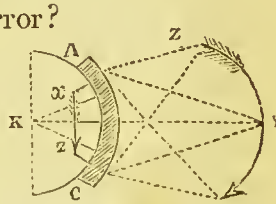


Fig. 18.

Ja. What would be the effect if, instead of an opaque object *x z*, a luminous one, as a candle, were placed in the focus of a concave mirror?

Fa. It would strongly illuminate a space of the same dimension as the mirror to a great distance; and if the candle were still nearer the mirror than the focus, its rays would enlighten a larger space. Hence you may understand the construction of many of the lamps which are now to be seen in many parts of London, and which are undoubtedly a great improvement in lighting the streets.

QUESTIONS FOR EXAMINATION.

How and where is the image formed in a concave mirror? — What is the rule for finding the distance at which the image of an object is formed from the mirror? — Can concave mirrors be applied as burning-glasses? — Is the image formed by a concave mirror always before it? — In what cases is the image behind the mirror? — What is the effect of a candle if placed in the focus of a concave mirror?

CONVERSATION XIII.

OF CONCAVE AND CONVEX MIRRORS.

Father. We shall devote another morning or two to the subject of reflection from mirrors of different kinds.

Ch. You have not said anything about *convex* mirrors; and yet they are now very much in fashion in handsome drawing-rooms. I remember seeing one, when I was at my uncle's, in which the images were very much less than the objects themselves.

Fa. A convex mirror is an ornamental piece of furniture, especially if it can be placed before a window, commanding a good prospect, or where there are a number of persons passing and repassing in their different employments. The images reflected from these are smaller than the objects, erect, and behind the surface; therefore a landscape, or a busy scene, delineated on one of them, is always a beautiful object. You may easily conceive how the convex mirror diminishes objects, or the images of objects, by considering in what manner they are magnified by the concave mirror. If X Y Z (fig. 18) were a straight object before a *convex* mirror, A C, the image by reflection would be *x z*.

Ja. Would it not appear curved?

Fa. Certainly: for if the object be a right line, or a plain surface, its image must be curved; because the different points of the object are not equally distant from the reflector. In fact, the images formed by convex mirrors, if accurately compared with the objects, are never exactly of the true shape.

Ch. I do not quite comprehend in what manner reflection takes place at a convex mirror.

Fa. I will endeavour, by a figure, to make it plain: C D represents a convex mirror standing at the end of a room, before which the arrow A B is placed on one side, or obliquely. Now tell me where the spectator must stand to see the reflected image?

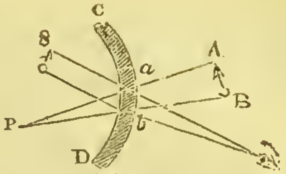


Fig. 19.

Ch. On the other side of the room.

Fa. The eye E will represent that situation:—the rays from the external parts of the arrow, A and B, flow convergingly along A *a* and B *b*; and if no glass were in the way, they would meet at P; but the glass reflects the ray A *a* along *a* E, and the ray B *b* along *b* E; and, as we always transfer the image of an object in the direction where the rays approach the eye, we see the image of A, along the line E *a*, behind the glass, and the image of B along E *b*; and, therefore, the image of the whole arrow appears at S.

By means of a similar diagram I will show you more clearly the principle of the *concave* mirror. Suppose an object *e* beyond the focus F, and the spectator to stand at Z, the rays *e b* and *e d* are reflected; and where they meet in E, the spectator will see the image.

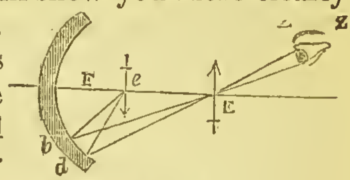


Fig. 20.

Ja. That is, between himself and the image.

Fa. He must, however, be far enough from it to receive the rays after they have diverged from E; because every enlightened point of an object becomes visible only by means of a cone of rays diverging from it: and we cease to see it if the rays become parallel or converging.

Ch. Is the image inverted?

Fa. Certainly: because the rays have crossed before they reach the eye.

You may see this subject in another point of view. Let *x y* be a concave mirror, and O the centre of concavity: divide O A equally in F, and take the half, the third, the fourth, &c., of F O, and mark these divisions, $\frac{1}{2}$, $\frac{1}{3}$, $\frac{1}{4}$, &c. Let A O be extended, and parts be taken in it equal to F O, at 2, 3, 4, &c. Now, if any of the

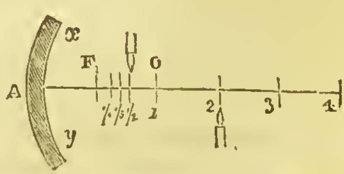


Fig. 21.

points, 1, 2, 3, 4, &c., be the focus of incident rays, the correspondent points, 1, $\frac{1}{2}$, $\frac{1}{3}$, $\frac{1}{4}$, &c., in O F will be the focus of the reflected rays, and *vice versa.*

Ja. Do you mean that if incident rays be at $\frac{1}{2}$ or $\frac{1}{3}$, or $\frac{1}{4}$, the reflected rays will be at 2, 3, 4.

Fa. I do: place a candle at 2, and an inverted image will be seen at $\frac{1}{2}$: now place it at 4, and it will also move back to $\frac{1}{4}$: these images may be taken on paper held in those respective places.

Ch. I see that the further you proceed one way with the candle, the nearer its inverted image comes to the point F.

Fa. True: and it never gets beyond it; for that is the focus of parallel rays after reflection, or of rays that come from an infinite distance.

Ja. Suppose the candle were at O?

Fa. Then the object and image would coincide: and as the image of an object between F and a concave speculum is on the other side of the speculum, this experiment of the candle and paper cannot be made.

I will now just mention another experiment. At one end of an oblong box, about two feet long, and fifteen inches wide, place a concave mirror. Near the upper part of the opposite end a hole is made, and in about the middle of the box is placed a hollow frame of pasteboard that confines the view of the mirror. The top of the box, next the end in which the hole is made, is covered with a glass; but the other half is darkened. Under the hole are placed in succession different pictures, properly painted, which are thrown into perspective by the mirror, and produce a beautiful appearance.

QUESTION FOR EXAMINATION.

Look to fig. 18, and tell me why the images of objects seen in convex mirrors are less than the objects themselves?

CONVERSATION XIV.

OF CONVEX REFLECTION—OF OPTICAL DELUSIONS—OF ANAMORPHOSES.

Charles. Can the same experiment be made with a candle and a convex mirror that you made yesterday with the concave one?

Fa. No; because the image is formed behind the glass; but it may, perhaps, be worth our while to consider how the effect is produced in a mirror of this kind. Let *a b* represent a convex mirror, and A *f* be half the radius of convexity, and take A F, F O, O B, &c., each equal to A *f*. If incident rays flow from 2, the reflected rays will appear to come from behind the glass at $\frac{1}{2}$.

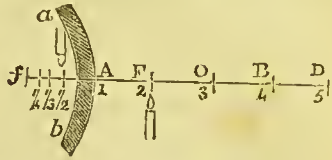


Fig. 22.

Ja. Do you mean that, if a candle be placed at 2, the image of it will appear to be formed at $\frac{1}{2}$, behind the glass?

Fa. I do; and if that, or any other object, be carried to 3, 4, &c., the image will also go backward to $\frac{1}{3}$, $\frac{1}{4}$, &c.

Ch. Then, as a person walks towards a convex spherical reflector, the image appears to walk towards him, constantly increasing in magnitude till they touch each other at the surface.

Fa. You will observe that the image, however distant the object, is never farther off than at *f*. That is the imaginary focus of parallel rays.

Ja. The difference, then, between convex and concave reflectors is, that the point *f* in the *former* is behind the glass, and in the latter it is before the glass, as F.

Fa. Just so: from the property of diminishing objects, spherical reflectors are not only pleasing ornaments for our rooms, but are much used by all lovers of picturesque scenery. "Small convex reflectors," says Dr. Gregory, in his *Economy of Nature*, "are made for the use of travellers, who, when fatigued by stretching the eye from mountain to mountain of the Alpine range, can by their mirror bring those sublime objects into a narrow compass, and gratify the sight by pictures which the art of man so vainly attempts to imitate."

Concave mirrors have been used for many different purposes; and, with a little ingenuity, a thousand optical illusions by means of them can be practised on the ignorant.

Ch. I remember going with you to see an exhibition in Bond-street, which you said depended on a concave mirror. I was desired to look into a glass. I did so, and started back; for I thought the point of a dagger would have been in my face. I looked again, and a death's head snapped at me; and then I saw a most beautiful nosegay, which I wished to grasp, but it vanished in an instant.

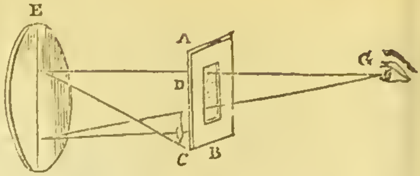


Fig. 23.

Fa. I will explain how these deceptions are managed. Let E F be a concave mirror, 10 or 12 inches in diameter, placed in one room; A B the wainscot that separates the spectator from it, in which there is a square or circular opening exactly facing the mirror. A nosegay, for instance, is now inverted at C, which must be strongly illuminated by means of an Argand lamp; but no direct light from the lamp is to fall on the mirror. A person standing at G will see an image of the nosegay at D.

Ja. What will cause it to vanish?

Fa. In exhibitions of this kind there is always a person behind the wainscot, in league with the man attending on the spectator, who, upon some hint, or signal, previously understood between them, removes the real nosegay.

Ch. Did, then, the approaching sword, and the advancing death's-head, &c., which so alarmed me, depend on the movements of the man behind the scene?

Fa. They did: and persons have undertaken to exhibit the ghosts of the dead by contrivances of this kind; for if a drawing of the deceased be put in the place of the nosegay, it may often be done. But such exhibitions are not to be recommended, and indeed ought never to be practised, particularly on ladies and nervous individuals, nor even on the stronger minded: the whole process ought to be explained to the astonished spectator afterwards.

If a large concave mirror be placed before a blazing fire, so as to reflect the image of the fire on the flap of a bright mahogany table, a spectator suddenly introduced in the room would suppose the fire to be on the table.

Fig. 24.

If two large concave mirrors, A and B, be placed opposite each other at the distance of several feet, and red-hot charcoal be put in the focus D, and some gunpowder in the other focus C, it will presently take fire. The use of a pair of bellows may be necessary to make the charcoal burn strongly. This experiment may be varied by placing a thermometer in one focus, and

lighted charcoal in the other; and it will be seen that the quicksilver in the thermometer will rise as the fire increases, though another thermometer at the same distance from the fire, but not in the focus of the glass, will not be affected by it.

Ja. I have seen concave glasses which rendered my face as long as my arm, or as broad as my body. How are these made?

Fa. These images are called *anamorphoses*, a term derived from two Greek words, *ana* (*ανα*), "backward," and *morphe* (*μορφη*), "a shape or form." They are produced from *cylindrical* concave mirrors; and as the mirror is placed either *upright* or on *its side*, the image of the picture is distorted into a very long or very broad image.

Reflecting surfaces may be made of various shapes, and if a regular figure be placed before an irregular reflector, the image will be deformed; but if an object, such as a picture, be painted deformed, according to certain rules, the image will appear regular and proportional. Such figures and reflectors are sold by opticians; and they serve to astonish those who are unacquainted with these subjects.

You must have now perceived that a surface may be so constructed that it shall reflect the rays of any one pencil of light in such a manner as to cause them to *converge* to a point, *diverge* from a point, or proceed *parallel* to each other.

Ch. Yes: that surface may be either plane or curved. But is there anything in common between the properties of convex lenses and those of concave mirrors?

Fa. There is, in a great measure; for convex lenses and concave mirrors form an inverted focal image of any remote object, by causing the convergence of the pencil of rays. Concave lenses and convex mirrors form, in general, an erect image in the virtual focus, by the divergence of the pencil of rays. In those telescopes which act by *the effects* of reflection, the concave mirror is used instead of the convex lens, and the convex mirror instead of the concave lens.

Ch. In what, then, do they differ?

Fa. They must necessarily, when combined, differ from the disposition of lenses, on account of the opacity of the one and the transparency of the other.

Ch. As we have already learned that in burning-glasses by *reflection* the burning-spot is merely the picture of the sun formed by a concave mirror held parallel to the disk of the sun; what, then, are we to understand as to the degree of heat at the luminous spot, when compared with the ordinary heat of the sun?

Fa. It is in proportion as the area of the mirror is to the area of the spot; because the spot is invariably in the middle, between the surface of the mirror and its centre. But this is to be understood only of the quantity of heat originally collected, which we must suppose to be augmented in the same manner as in burning-glasses by *refraction*.

QUESTIONS FOR EXAMINATION.

What is the appearance if a person walks towards a convex spherical reflector? — Does the distance of the image increase in proportion to the distance of the object? — What is the difference between convex and concave reflectors? — To what uses have convex reflectors been applied? — What are concave mirrors used for? — How are anamorphoses produced?

CONVERSATION XV.

OF THE DIFFERENT PARTS OF THE EYE.

Charles. Will you now, Papa, describe the nature and construction of the telescope?

Fa. I think it will be better first to explain the several parts of the eye, and the nature of vision in the simple state, before we treat of those instruments which are designed to assist it.

Ja. I once saw a bullock's eye dissected, and was told that it was just like the human eye in the construction of its several parts.

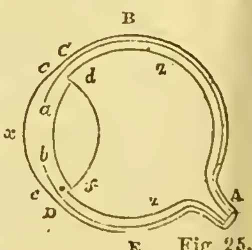


Fig 25.

Fa. The eye, when taken from the socket, is nearly of a globular form, and composed of three external coats or skins, and three internal substances, called humours. This figure represents the section of an eye; that is, an eye cut through the

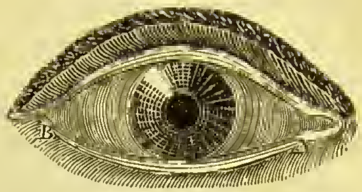


Fig. 26.

middle; and this the front view of the eye, as it appears in the head.

Ch. Have these coats and humours all different names?

Fa. Yes: the external coat, which is represented by the outer circle, A B C D E, is called the *sclerotica*, or sclerotic membrane, from the Greek word *scleros* (σκληρός), "hard:" it is the hard outer coating; the front part, C x D, is perfectly transparent; and is called the *cornea;* beyond this, towards B and E, it is white, and called the white of the eye. The next coat, which is represented by the second circle, is called the *choroid membrane*, forming the interior coating of the sclerotic.

Ja. This circle does not go all round.

Fa. No: the vacant space, *a b*, is that which we call the pupil; and through this alone the light enters the eye.

Ch. What do you call that part which is of a beautiful blue in some persons, and in others brown, or almost black?

Fa. That (as *a c*, *b e*,) is part of the *choroid membrane*, and is called the *iris*, from possessing various colours.

Ch. How is it that the iris is sometimes much larger than it is at another?

Fa. It is composed of a peculiar structure, which contracts or expands according to the intensity of the light which is present. Let your brother stand in a dark corner for two or three minutes, and then look at his eyes.

Ch. The *iris* of each, I perceive, is very small, and the pupil large.

Fa. Now let him look steadily pretty close to the candle.

Ch. The *iris* is considerably enlarged, and the pupil of the eye is but a small point in comparison of what it was before.

Fa. Did you never feel a peculiar affection of the eyes when candles were suddenly brought into the room, after you had been sitting some time in the dark?

Ja. Yes, on several occasions; and others with me have felt the same.

Fa. By sitting so long in the dark, the iris had become very much contracted, and the pupil being large, more light

was admitted than it could well bear, and therefore, till time was allowed for the iris to adjust itself, the peculiar sensation would be felt.

Ch. What do you call the third coat, which, from the figure, appears to be still less than the choroid membrane?

Fa. It is called the *retina*, from the Latin term for net-work. It forms a pulpy film, which serves to receive the images of objects which are produced by the refraction of the different humours of the eye, and are painted, as it were, on the surface.

Ch. Are the humours of the eye intended for refracting the rays of light, in the same manner as glass lenses?

Fa. They are; and they are called the *vitreous* and *aqueous* humours, and the *crystalline* lens. The *vitreous* humour fills up all the space, z z, at the back of the eye; it is nearly of the same refractive power as glass. The *crystalline* lens is represented by *d f*, in the shape of a double convex lens: and the *aqueous*, or watery humour, fills up all that part of the eye between the crystalline lens and the cornea C *x* D.

Ja. What does the part A, at the back of the eye, represent?

Fa. It is the optic nerve, which serves to convey to the brain the sensations produced on the retina, and by and by we shall endeavour to explain the office of these humours in effecting vision. In the meantime, I would request you to consider again what I have told you of the different parts of the eye, and examine, at the same time, both the figures, 25 and 26.

Ja. We will: but you have said nothing about the uses of the eye-brows and eye-lashes.

Fa. I intended to reserve this till another opportunity, but I may now say that the eye-brows, called the *supercilia*, defend the eye from too strong a light, and likewise prevent the injuries that might happen by the sliding of substances down the forehead into the eyes.

The eye-lids act like curtains to cover and protect the eyes during sleep. When we are awake, they diffuse a fluid over the eye, which keeps it clean and well adapted for transmitting the rays of light.

The eye-lashes, or *cilia*, in a thousand instances, guard the

eye from danger, and protect it from floating dust, with which the atmosphere abounds.

QUESTIONS FOR EXAMINATION.

Of what is the eye composed? — Which is the sclerotica? — Which is the cornea, and why is it so called? — Which is the choroid membrane? — Which is the part called the iris? — Why is the aperture within this larger at one time than at others? — Why do we feel uneasiness if we are suddenly introduced to the light after having been some time in the dark? — Which is the retina, and what is its use? — For what are the humours of the eye intended? — What are the names given to them? — Which is the vitreous humour, and why is it so called? — What is the crystalline humour? — How is the aqueous humour situated? — What is the optic nerve for? — Describe the uses of the eye-brows, the eye-lids, and eye-lashes.

CONVERSATION XVI.

OF THE EYE, AND VISION.

Charles. I do not understand what you meant when you said that the optic nerve served to convey to the brain the sensations produced on the retina.

Fa. Nor do I pretend to tell you in what manner the image of any object painted on the retina of the eye is calculated to convey to the mind an idea of that object: but I wish to show you that the images of the various objects which you see are painted on the retina. Here is a bullock's eye, from the back part of which I cut away the three coats, but so as to leave the vitreous humour perfect. I will now put against the vitreous humour a piece of white paper, and hold the eye towards the window. What do you see?

Ja. The figure of the window is drawn upon the paper, but it is inverted.

Fa. Open the window, and you will see the trees in the garden, or any other bright object, drawn upon it in the same inverted position.

Ch. Does the paper, in this instance, represent the innermost coat, called the retina?

Fa. It does: and I have made use of paper, because it is easily seen through; whereas the retina being opaque, transparency would be of no advantage to it. The retina, by means of the optic nerve, conveys the images depicted on it to the brain, and it is nothing more nor less than an expansion of the optic nerve.

Ja. And does it convey the idea of every object that is painted on the retina?

Fa. It is imagined to do so; for we have an idea of whatever is drawn upon it. When I direct my eyes to you, the image of your person is painted on the retina of my eye, and, therefore, I make use of the expression, "I see you." So of anything else.

Ch. You said the rays of light proceeding from external objects were refracted in passing through the different humours of the eye.

Fa. They are, and converged to a point, or there would be no distinct picture drawn on the retina, and of course no distinct idea conveyed to the mind. I will show you what I mean by this figure; taking an arrow again as an illustration.

As every point of an object A B C sends out rays in all directions, some rays from each point on the side next the eye will fall upon the cornea between *x y*, and, by passing through the humours of the eye, will be converged and brought to as many points on the retina, and will form on it a distinct inverted picture, *c*, *b*, *a*, of the object.

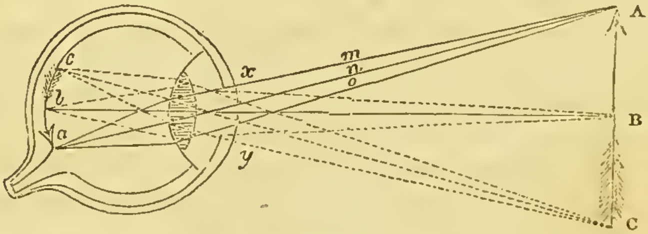


Fig. 27.

Ja. This is done in the same manner as you showed us, by means of a double convex lens.

Fa. Yes, all three of the humours have some influence in refracting the rays of light; but the crystalline is the most powerful, and that is a double convex lens: you see that the rays from A are brought to a point at *a*, those from B will be converged at *b*, and those from C at *c*, and of course the intermediate rays between A and B, and B and C will be formed between *a* and *b*, and *b* and *c*. Hence the object becomes visible by means of the image of it drawn on the retina.

Ch. Since the image is inverted on the retina, how is it that we see things in the proper position?

Fa. That is a proper question, but one that is not very readily answered. It is well known that the sense of touch or feeling very much assists the sense of sight. Some paintings are so exquisitely finished, and so much resemble sculpture, that the eye is completely deceived. We then naturally extend the hand to aid the sense of seeing. Children, who have to learn the use of all their senses, make use of their hands in everything: they see nothing which they do not wish to handle; and therefore it is not improbable that by the sense of the touch they learn, unawares, to rectify that of seeing. The image of a chair or table, or any other object, is painted in an inverted position on the retina: they feel and handle it, and find it erect; the same result perpetually recurs; so that, at length, long before they can reason on the subject, or even describe their feelings by speech, the inverted images give them an idea of an erect object.

Ch. I can easily imagine that this would be the case with common objects, such as are seen every day and every hour. But will there be no difficulty in supposing that the same must happen with regard to anything which I had never seen before? I never saw ships sailing on the sea till within this month; but when I first saw them, they did not appear to me in an inverted position.

Fa. But you have seen water and land before; and they appear to you, by habit and experience, to be lowermost, though they are painted on the eye in a different position; and the bottom of the ship is next the water, and consequently, as you refer the water to the bottom, so you must the hull of the ship which is connected with it. In the same manner all the parts of a distant prospect are right with respect to each other; and therefore, though there may be a hundred objects in the landscape entirely new to you, yet, as they all bear a relation to one another, and to the earth on which they are, you refer them, by experience, to an erect position.

Ja. How is it that, in so small a space as the retina of the eye, the images of so many objects can be formed?

Fa. Dr. Paley,* in his Natural Theology, tells us, "The prospect from Hampstead Hill is compressed into the compass of a sixpence, yet circumstantially represented. A stage

* See Paley's Natural Theology, p. 35, 7th edit., or p. 13, in the Analysis of that work, by the author of these Dialogues.

coach, travelling at its ordinary rate, for half an hour, passes in the eye only over one twelfth part of an inch, yet the change of place is distinctly perceived throughout its whole progress." This assertion we all know to be true. Go to the window and look steadily at the prospect before you, and see how many objects you can discern without moving the eye.

Ja. I can see a great number very distinctly indeed; besides which, I can discern others, on both sides, which are not so clearly defined.

Ch. I find another difficulty. We have two eyes; on both of which the images of objects are painted. How is it that we do not see every object double?

Fa. When an object is seen distinctly with both eyes, their axes are directed to it, and the object appears single; for the optic nerves are so constructed, that the correspondent parts, in both eyes, lead to the same place in the brain, and excite but one sensation. But if the axes of both eyes are not directed to the object, that object seems double.

Ja. Does that ever occur?

Fa. Look at your brother, while I push your right eye a little out of its place towards the left.

Ja. I see two brothers; the one receding to the left hand of the other.

Fa. The reason is this: by pushing the eye out of its natural place, the pictures in the two eyes do not fall upon correspondent parts of the retina, and therefore the sensations from each eye are excited in different parts of the brain.

You now understand pretty clearly, I hope, the effect of different lenses, in distributing or collecting rays of light; and as the eye is formed of lenses, in the different humours it contains, you have, doubtless, a much better idea of the action of that important organ than you had before.

Ch. But what are the particular uses of the *vitreous* and *aqueous* humours, and of the *crystalline* lens, you have alluded to?

Fa. The chief use of the aqueous or watery humour is apparently to preserve the proper curvature of the *tunica cornea*, so as to allow of the undisturbed motions of the iris which floats in it. It is a *meniscus*, and embraces the anterior portion of the crystalline lens. Its anterior surface is covered

by the cornea, which forms the anterior transparent portion of the eye.

Ch. What is the peculiar use of the crystalline lens?

Fa. It performs the important office of accurately conveying the rays of light to the surface of the retina, and is a double convex lens formed from unequal radii, the convexity from the shorter radius being placed inwards. Its refractive density is greater than those of the humours that surround it.

Ch. What is the use of the vitreous or glassy humour?

Fa. It is apparently to keep the crystalline lens at such a distance, as to make the rays of light fall on the retina, and also to spread the retina smoothly before the light. It is also a meniscus. It embraces in its concave surface, the internal convexity of the crystalline lens, and its convex surface is surrounded by the retina.

Ch. I have often heard mention of the *ciliary* ligament; what does that mean, Papa?

Fa. It is a white ligament attached to the circumference of the crystalline lens. The *sclerotica*, or external tunic or coat of the eye, is to preserve, by its hardness, the globular figure of the organ, and by its strength and elasticity, the delicate parts of the interior are defended. It forms the white of the eye.

Ch. What is the use of the *cornea*, Papa?

Fa. Its use is to cover the front of the eye, and it may with reason be termed its window; the plates of which it is composed being of the most brilliant transparency. It is so hard, that it will sometimes break the point of a needle, when applied to it for any operation; and by this quality it defends the eye from injury. Through its colourless transparency, the rays of light find an easy passage to the retina.

The choroid membrane adheres to the sclerotica within, and at the circumference of the cornea joins the iris through the ciliary ligament. It is composed of two layers, the inner of which secretes a peculiar substance, called the *pigmentum nigrum*, or black pigment, which is spread over the whole inner surface of the eye, in immediate contact with the retina. Its use is to absorb all those rays of light which would otherwise have been reflected from the surface of the retina, and interfered with the perfect formation of the image.

Ja. What is the use of the iris, Papa?

Fa. It is to regulate the quantity of light admitted by the aperture in its centre, called the pupil; and it takes its name as I have before observed, on account of its variety and beauty, the colour depending on the reflection of light from the velvet like surface of the membrane.

Ja. What did you say, Papa, the third or inner coat of the eye was composed of, which you called the retina?

Fa. It is an expansion of the optic nerve, consisting of a thin membrane covered with numerous veins, arteries, and absorbent vessels, upon which the threads of the optic nerve are wrought into a delicate and beautiful net-work. The retina is the seat of vision, on which all external images are refracted by the different humours of the eye, and painted as it were, upon its surface.

Ch. But what is the reason we hear some people complain of being short-sighted?

Fa. Short-sightedness arises from too great a convexity of the cornea, and too great a density of the crystalline lens by both of which the visual rays from near objects are brought to a focus before they reach the retina.

Ch. And why are old persons often long-sighted?

Fa. Because their eyes lose the power of adjusting themselves to short distances, as they advance in age; the cornea gradually becoming flatter, and the power of the crystalline lens diminishing.

Ch. How is the eye moved?

Fa. By means of muscles: there are four denominated *straight*, and two *oblique*, the former to direct the motions of the eye upwards, downwards, and laterally, and the latter to govern its oblique movements. The four straight muscles when acting together, retract the eye-ball and slightly compress it, so as to enable it to accommodate itself to various distances.

Ch. What are tears?

Fa. Tears are composed of a fluid, which a kind Providence has given us for the purpose of moistening the surface of the eye-ball, and cleansing it of its impurities, by the aid of the action of the eye-lids.

Ch. What produces this fluid?

Fa. It is secreted from a gland situated in the hollow of a bone, just under the outer end of the brow; and called the

lachrymal gland, the peculiar office of which is to secrete the fluid from the blood, into a number of small tubes or ducts, which convey it as circumstances of excitement or accident may require.

Ch. Is this discharge necessary during sleep?

Fa. If the fluid were not kept from the eye during sleep, it might be fatal to the sight. The same Providence which has supplied the tears, has provided for all emergencies. When the eye-lids are closed, the fluid is collected in the inner angles of the eyes, and absorbed by capillary attraction into the small holes, called the *puncta lachrymalia*, then discharged into a receptacle, called the lachrymal sac, and thence emptied into the nostril, where it is speedily evaporated by the constant passage of warm air produced in breathing.

Ch. What is the use of the eye-brows?

Fa. They prevent the perspiration collected on the brows during fatigue, from falling into the eyes, which might be irritated by it.

Ch. What reason can be given for the variation in the form and colour of the eyes in people of different nations?

Fa. There can be little doubt that the wise intention of the Creator was thereby to adapt them to the difference of climate, where the same kind of eye would be unable to adapt itself to a greater or less degree of light and heat.

QUESTIONS FOR EXAMINATION.

How is the image of any object painted on the retina of the eye? — Show me, by fig. 27, how the rays of light are refracted in passing through the different humours of the eye. — Do all the humours refract the rays of light, and which has the greatest effect upon them? — How is it that we see the images of objects in the proper erect position, since they are inverted on the retina? — Is there no difficulty in reconciling this theory to objects never seen before? — Why do we not see objects double? — By what means do we see objects double?

CONVERSATION XVII.

OF SPECTACLES, AND OF THEIR USES.

Charles. Why do people wear spectacles?

Fa. To assist the sight, which may be defective from various causes. Some eyes are too flat, others are too convex:

in some the humours lose a part of their transparency, and on that account much of the light that enters the eye is stopped, and so lost in the passage that every object appears dim. The eye, without light, would be a useless machine. Spectacles are intended to collect the light, or to assist the eye in bringing it to a proper degree of convergency, where that organ cannot refract it sufficiently.

Ch. Are spectacle-glasses always convex?

Fa. No: they are convex when the eyes are too flat; but if the eyes are already very convex, then concave glasses are used. You know the properties of a convex glass?

Ja. Yes; it is to make the rays of light converge sooner than they otherwise would.

Fa. Suppose, then, a person unable to see objects distinctly, owing to the cornea C D, or to the crystalline lens, *a b*, or both, being too flat. The focus of rays proceeding from any object, *x*, will not be on the retina, where it ought to be, but at *z*, beyond it.

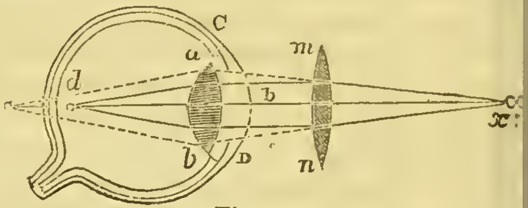


Fig. 28.

Ch. How can it be beyond the eye?

Fa. It would be beyond it, if there were anything to receive it. As it is, the rays flowing from *x* will not unite at *d*, so as to render vision distinct. To remedy this, a convex glass, *m n*, is placed between the object and the eye; by means of which the rays are brought to a focus sooner, and the image is formed at *d*.

Ja. Now I see the reason why people are obliged, sometimes, to make trial of many pairs of spectacles before they get those that will suit them. They cannot tell exactly what degree of convexity is necessary to bring the focus just to the retina.

Fa. You are right; for the shape of the eye may vary as much as that of their countenance. Of course, a pair of spectacles that might suit you would not be adapted to another, whose eyes should require a similar aid. What is the property of concave glasses?

Ch. They cause the rays of light to diverge.

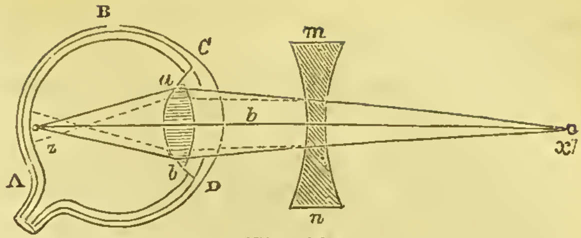


Fig. 29.

Fa. Then, for very round and globular eyes, these will be useful; because, if the cornea, C D, or crystalline lens, *a b*, be too convex, the rays flowing from *x* will unite into a focus before they arrive at the retina, as at *z*.

Ch. If the sight, then, depend on sensations produced on the retina, such a person will not see the object at all, because the image of it does not reach the retina.

Fa. True: but at *z* the rays cross one another, and pass on to the retina, where they will produce some sensations, but not those of distinct vision, because they are not brought to a focus there. To remedy this, the concave glass *m n* is interposed between the object and the eye, which causes the rays coming to the eye to *diverge*, and, being more divergent when they enter the eye, it requires a very convex cornea or crystalline lens to bring them to a focus at the retina.

Ja. I have seen old people, when examining an object, hold it a good distance from their eyes.

Fa. Because, their eyes being too flat, the focus is thrown beyond the eye, and therefore they hold the object at a distance to bring the focus *z* (fig. 28) to the retina.

Ch. Very short-sighted people bring objects close to their eyes.

Fa. Yes; I once knew a young man who was accustomed, when looking at his writing, to blot with his nose what he had written with his pen. In this case, bringing the object near the eye produces a similar effect to that produced by concave glasses: because, the nearer the object is brought to the eye, the greater is the angle under which it is seen; that is, the extreme rays, and of course all the others, are made more divergent.

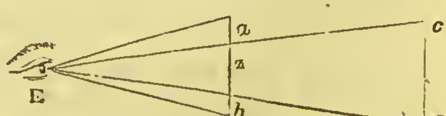


Fig. 30.

If you imagine E to be the eye, and the object *a b*, seen at *z*, and also at *x*, double the distance, will not the

same object appear under different angles to an eye so situated?

Ja. Yes, certainly; *a* E *b* will be larger than *c* E *d*, and will include it.

Fa. Then the object brought very near the eye has the same effect as magnifying the object, or of causing the rays to diverge; that is, though *a b* and *c d* are of the same length, yet *a b*, being nearest to the eye, will appear the largest.

Ch. You say that the eyes of old people become flat by age. Is that the progress of nature?

Fa. It is; and therefore people who are very short-sighted while young, will probably see well when they grow old.

Ja. That is an advantage denied to ordinary eyes.

Fa. But people blessed with ordinary sight should be thankful for the benefit they derived while young.

Ch. And I am sure we cannot too highly estimate the science of optics, which has afforded such assistance to defective eyes, which, in many circumstances of life, would be useless without them.

Fa. When, and by whom spectacles were invented, is not accurately known; they seem to have been introduced in the 13th century, and some assign the invention to Roger Bacon, about 1280.

QUESTIONS FOR EXAMINATION.

In what way do spectacles assist the sight? — Of what form are spectacle-glasses? — Explain how a person may have his sight assisted whose eye is too flat. — Why do the people try many pairs of spectacles before they suit themselves? — Explain, by fig. 29, how a person with eyes too round would meet with a remedy in spectacles. — Why do some old people in examining small objects hold them at a distance from the eye? — Why do short-sighted people bring objects close to their eyes? — Explain this by fig. 30. — Why do people who were short-sighted while young see better as they advance in years?

CONVERSATION XVIII.

OF THE RAINBOW.

Father. You have frequently seen a rainbow?

Ch. Oh, yes, and very often two at the same time, one above the other; the lower one by far the most brilliant.

Fa. This is, perhaps, the most beautiful meteor in nature.

It never makes its appearance but when a spectator is situated between the sun and the shower.

Ja. Is a rainbow occasioned by the falling drops of rain?

Fa. Yes; it depends on the reflection and refraction of the rays of the sun by the falling drops.

Ch. I know now how the rays of the sun are *refracted* by water. Are they also *reflected* by it?

Fa. Yes; water, like glass, reflects some rays, while it transmits or refracts others. You know the beauty of the rainbow consists in its colours.

Ja. Yes; "the colours of the rainbow" is a very common expression. I have been told that there are seven of them; but it is seldom that so many can be clearly distinguished.

Fa. Perhaps that is owing to your want of patience. I will show you the colours first by means of the prism. If a ray of light, s, be admitted into a darkened room, through a small hole in the shutter, *xy*, its natural course is along the line to *d;* but if a glass prism, *ac*, be introduced, the whole ray will be bent upwards, and if it be received on any white surface, as M N, it will form an oblong image, P T, the breadth of which is equal to the diameter of the hole in the shutter.

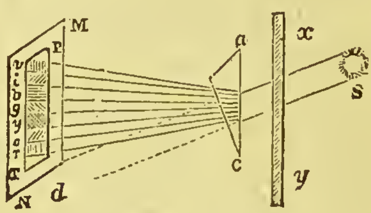


Fig. 31.

Ch. This oblong is of different colours in different parts.

Fa. These are the colours of the rainbow.

Ja. But how is the light which is admitted by a *circular* hole in the window spread out into an oblong?

Fa. If the ray were of one uniform substance, it would be equally bent upwards, and make only a small circular image. Since, therefore, the image or picture is oblong, it is inferred that it is formed of rays differently refrangible, some of which are turned more out of the way, or more upwards than others; those which go to the upper part of the spectrum being most refrangible; those which go to the lowest part are the least refrangible: the intermediate ones possess more or less refrangibility. Can you distinguish the seven colours?

Ch. Yes; here are the *violet, indigo, blue, green, yellow, orange,* and *red.*

Fa. These colours would be still more beautiful if a convex

lens were interposed, at a proper distance, between the shutter and the prism.

Ja. How does this apply to the rainbow?

Fa. Suppose A to be a drop of rain, and Sd a ray from the sun falling upon or entering it at d, it will not go to c, but be refracted to n, where a part will emerge; but a part also will be reflected to q, where it will go out of the drop, which, acting like a prism, separates the ray into its primitive colours, and the violet will be uppermost, the red lowermost.

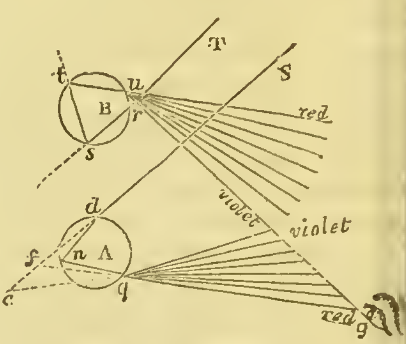


Fig. 32.

Ch. Is it at any particular angle that these colours are formed?

Fa. Yes; they are all at fixed angles: the least refrangible, or red, makes an angle with the solar incident ray, equal to a little more than 42 degrees; and the violet, or most refrangible ray, will make with the solar ray an angle of 40 degrees: thus—the ray Sd proceeds to fc; therefore the angle made with the red ray is Sfq, and that made with the violet ray is Scq; the former being 42° 2′, the latter 40° 17′.

Ch. Is this always the case whether the sun is higher or lower in the heavens?

Fa. It is. but the situation of the rainbow will vary according as the sun is high or low; that is, the higher the sun the lower will be the rainbow: a shower has been seen on a mountain by a spectator in a valley, by which a complete circular rainbow has been exhibited.

Ja. And I remember once standing on a lofty hill when there was a heavy shower, and while the sun shone very bright, all the landscape beneath, to a vast extent, seemed to be painted with the prismatic colours.

Ch. You have not explained the reason of the upper or fainter bow.

Fa. The two bows have the name of the *primary* and the *secondary* rainbow: the latter is formed by two refractions and two reflections. Suppose the ray Tr to be entering the drop B at r. It is refracted at r, reflected at S, reflected again at

and refracted as it goes out at *u*, which will account for its appearance to the spectator as at *g*. Here, however, the colours are reversed; the angle formed by the red ray is 51°, and that formed by the violet is 54°.

Ja. Does the same thing happen with regard to a whole shower, as you have shown with respect to the two drops?

Fa. Certainly: and by the constant falling of the rain, the image is preserved constant and perfect. Here is the representation of the two bows. The rays come in the direction S A, and the spectator stands at E with his back to the sun, or, in other words, he must be between the sun and the shower.

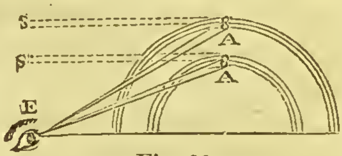


Fig. 33.

This may be illustrated in another way. If a glass globule filled with water be hung sufficiently high to appear red before you, when the sun is behind, let it descend gradually, and you will see, in the descent, all the other six colours follow one another. Artificial rainbows may be made with a common watering pot, but much better with a syringe fixed to an artificial fountain; and I have seen one by spirting up water from the mouth. It is often seen in cascades, in the foaming of the waves of the sea, in fountains, and even in the dew on the grass.

Dr. Langwith has described a rainbow which he observed lying on the ground; the colours of which were almost as lively as those of the common rainbow. It was extended several hundred yards; and the colours were so strong, that it might have been seen much further if it had not been terminated by a bank and the edge of a field.

Rainbows have also been produced by the reflection of the sun's beams from a river: and Mr. Edwards describes one which must have been formed by the exhalations from the city of London, when the sun had been set twenty minutes.

I may observe here that the light which passes through drops of rain, by two refractions without reflection, will appear strongest at the distance of about twenty-six degrees from the sun, and it will diminish gradually both ways as the distance from the sun increases and decreases. The same is to be understood of light transmitted through spherical hailstones: and if the hail be somewhat flat instead of round, the

light transmitted may increase so much, at a little less distance than twenty-six degrees, as to form a halo about the sun and moon; which halo, when the hailstones are duly figured, will probably be coloured—red within, by the least refrangible rays, and violet without, by those the most refrangible. The light which passes through a drop of rain, after two refractions, and two or more reflections, is scarcely strong enough to cause a sensible bow.

Ja. I have sometimes noticed different colours in the clouds as well as in rainbows. What is the cause of this, Papa?

Fa. When vapours are first raised by the heat of the sun, each single particle has a repelling force, keeping the other particles at a distance, which causes the atmosphere to be transparent, although the vapours are suspended in it, each particle being too small to cause reflection: but when the vapours are condensed by cold, and the single particles unite with each other, and form watery globules of different sizes, those globules, according to their various sizes, will reflect some colours and transmit others; thereby constituting clouds of different colours.

QUESTIONS FOR EXAMINATION.

When are rainbows seen?—By what is a rainbow occasioned, and on what does it depend?—How many colours are there in the rainbow?—Can you explain, by fig. 31, how a ray of light is divided by the prism?—Why is the image oblong?—Show, by fig. 32, how this is applicable to the rainbow.—At what particular angles are the colours formed?—Does the situation of the rainbow vary in proportion to the height of the sun?—Is the rainbow ever seen below the spectator?—How do you account for the upper bow?—Show how it happens by the figure.—By what means is the image of the rainbow preserved perfect and constant?—How are artificial rainbows produced?

CONVERSATION XIX.

OF THE REFRACTING TELESCOPE.

Father. We now come to describe the structure of telescopes, of which there are two kinds,—viz., the *refracting* and the *reflecting* telescope.

Ch. The *refracting* telescope depends, I suppose, upon

lenses for the operation; and the *reflecting* telescope acts chiefly by means of *mirrors.*

Fa. These are the general principles by which they are distinguished; and we will now devote a little time to the explanation of the *refracting* telescope. Here is one, completely fitted up.

Ja. It consists, I perceive, of two tubes and two glasses.

Fa. The tubes are intended to hold the glasses, and to confine the view. I will therefore explain the principle by the following figure, in which is represented the eye, A B, the two lenses, *mn*, *o q*, and the object, X Y. The lens, *o q*, which is nearest to the object, is called the object-glass, and that, *mn*, nearest to the eye, is called the eye-glass.

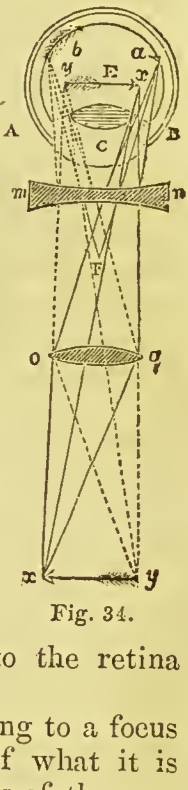


Fig. 34.

Ch. Is the object-glass a double convex, and the eye-glass a double concave lens?

Fa. It happens so in this particular instance; but it is not necessary that the eye-glass should be concave: the object-glass must, however, in all cases, be convex.

Ch. I see exactly, from the figure, why the eye-glass is concave: for the convex lens converges the rays too quickly, and the focus by that glass alone would be at E: and therefore the concave lens is put near the eye, to make the rays diverge so much as to throw them to the retina before they come to a focus.

Fa. But that is not the only reason: by coming to a focus at E, the image is very small, in comparison of what it is when the image is formed on the retina by means of the concave lens. Can you explain the reason of all the lines which you see in the figure?

Ja. I think I can. There are two pencils of rays flowing from the extremities of the arrow, which is the object to be viewed. The rays of the pencil, flowing from *x*, go on diverging till they reach the convex lens, *oq*, when they will be so refracted, by passing through the glass, as to converge, and meet in the point *x*. Now the same may be said of the pencil of rays proceeding from *y*; and, of course, of all the

pencils of rays flowing from the object between x and y. So that the image of the arrow would, by the convex lens, be formed at E.

Fa. And what would happen if there were no other glass?

Ja. The rays would cross each other and be divergent; so that, when they reached the retina, there would be no distinct image formed, but every point, as x or y, would be spread over so large a space, as to cause the image to be confused. To prevent this, the concave lens mn is interposed; the pencil of rays which would, by the convex glass, converge at x, will now be made to diverge, so as not to come to a focus till it arrives at a; and the pencil of rays which would, by the convex glass, have come to a point at y, will, by the interposition of the concave lens, be made to diverge so much as to throw the focus of the rays to b instead of y. It is thus that the image of the object is magnified.

Fa. Can you tell the reason why the tubes require to be drawn out more or less for different persons?

Ch. The tubes are to be adjusted in order to throw the focus of rays exactly on the retina: and as some eyes are more convex than others, the length of the focus will vary in different persons; and, by sliding the tube proportionally up or down, this object is obtained.

Fa. Refracting telescopes are used chiefly for viewing terrestrial objects: two things, therefore, are requisite in them: the *first* is, that they should exhibit the objects in an upright position; that is, in the same position as we see them without glasses; and the second is, that they should afford a large *field of view.*

Ja. What do you mean by a field of view?

Fa. I mean all that part of a landscape which may be seen at once, without moving the eye or instrument. Now, in looking at the figure again, you will perceive that the concave lens throws a number of the rays beyond the pupil, C, of the eye, upon the iris on both sides; but those only are visible, or help to form an image, which pass through the pupil; and therefore, by a telescope made in this way, the middle part of the object only is seen, or, in other words, the prospect is very much diminished.

Ch. How is that remedied?

Fa. By substituting a double convex eye-glass, *gh*, instead of the concave one. Here the focus of the double convex lens is at E, and the glass *gh* must be so much more convex than *op*, that its focus may be also at E: for then the rays flowing from the object *xy*, and passing through the object glass *op*, will form the inverted image *m* E *d*. Now, by interposing the double convex *gh*, the image is thrown on the retina, and is seen under the large angle D *e* C; that is, the image *m* E *d* will be magnified to the size C E D.

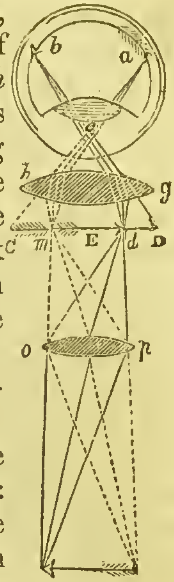


Fig. 35.

Ja. Is not the image of the object in the telescope inverted?

Fa. It is: for you see that the image on the retina stands in the same position as the object: but we always discern objects by having the images inverted: and, therefore, whatever is seen by telescopes, constructed as this is, will appear inverted to the spectator, which is a very unpleasant circumstance with regard to terrestrial objects. On that account it is chiefly used for celestial observations.

C. Is there any rule for calculating the magnifying power of this telescope?

Fa Yes: it magnifies in proportion as the focal distance of the object-glass is greater than the focal distance of the eye-glass. Thus, if the focal distance of the object-glass is ten inches, and that of the eye-glass only a single inch, the telescope magnifies the *diameter* of an object ten times; and the *whole surface* of the object will be magnified a hundred times.

Ch. Will any small bright object appear a hundred times larger through this telescope than it would by the naked eye?

Fa. Telescopes, in general, represent terrestrial objects to be *nearer* and not *larger*. Thus, looking at any object a hundred yards distant, it will not appear to be larger, but its distance will appear to be no more than a single yard.

Ja. Is there no advantage gained if the focal distance of the eye-glass and that of the object-glass be equal?

Fa. None: and therefore, in telescopes of this kind, we have only to increase the focal distance of the object-glass,

and to diminish the focal distance of the eye-glass, to augment the magnifying power to almost any degree.

Ch. Can you carry this principle to any extent?

Fa. Not altogether so. An object-glass of ten feet focal distance will require an eye-glass whose focal distance is rather more than two inches and a half: and an object-glass with a focal distance of a hundred feet must have an eye-glass whose focus must be about six inches from it. Can you tell me how much each of these glasses will magnify?

Ch. Ten feet, divided by two inches and a half, give for a quotient forty-eight; and a hundred feet, divided by six inches, give two hundred: hence one magnifies 48 times, and the other 200 times.

Fa. Refracting telescopes, for viewing terrestrial objects, in order to show them in their natural posture, are usually constructed with one object-glass and three eye-glasses; the focal distances of these last being equal.

Ja. Do you make use of the same method as you did in the last in calculating the magnifying power of a telescope constructed in this way?

Fa. Yes: the three glasses next the eye having their focal distances equal, the magnifying power is found by dividing the focal distance of the object-glass by the focal distance of one of the eye-glasses.

Ch. What is the construction of opera-glasses generally used at theatres and concerts?

Fa. The opera-glass is nothing more than a short refracting telescope.

The *night* telescope is not more than two feet long. It represents objects inverted, much enlightened, but not greatly magnified; and it is used to discover objects not very distant, but which cannot otherwise be seen from the want of sufficient light.

QUESTIONS FOR EXAMINATION.

How many kinds of telescopes are there? — What is the principle of each? — Of what does the refracting telescope consist? — For what are tubes meant? — Explain the construction of that represented in fig. 34. — What is the form of the object-glass? — Try and explain the several lines in the figure. — Why is it necessary to draw out the tubes of a telescope to adapt the telescope to the eyes of different people? — For what are refracting telescopes used, and what are the necessary requisites in them? — What is meant by the field of view? — Can you, by fig. 35, show how the field of view is increased? — How

is the magnifying power of a telescope calculated? — Do telescopes represent terrestrial objects *nearer* or *larger?* — How is the magnifying power of a telescope increased? — How are refracting telescopes, intended for viewing terrestrial objects, constructed? — Do you know how an opera-glass is constructed? — What is meant by a night-telescope?

CONVERSATION XX.

OF REFLECTING TELESCOPES.

Father. This is a telescope of a different kind, and is called a *reflecting* telescope.

Ch. What advantages does the reflecting telescope possess over that which you described yesterday?

Fa. The great inconvenience attending refracting telescopes is their length; and on that account they are not very much used when high powers are required. A reflector of six feet long will magnify as much as a refractor of a hundred feet.

Ja. Are these, like the refracting telescopes, made in various ways?

Fa. They were invented by Sir Isaac Newton, but they have been greatly improved since his time. The following figure will lead to a description of one of those most in use.

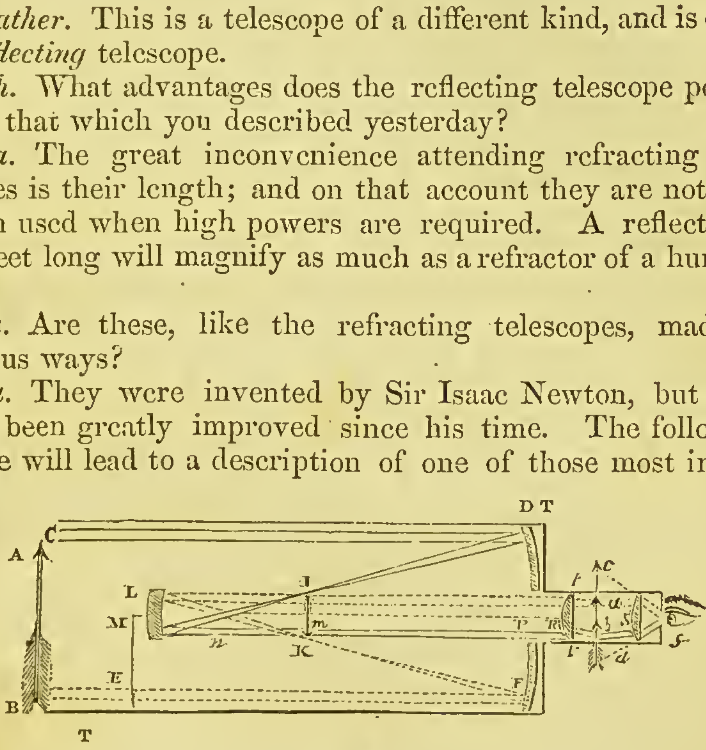


Fig. 36

You know that there is a great similarity between *convex lenses* and *concave mirrors.*

Ch. They both form an inverted focal image of any remote object, by the convergence of the pencils of rays.

Fa. In instruments, the exhibitions of which are the effects of reflection, the concave mirror is substituted for the convex lens: T T (fig. 36) represents the large tube, and *t t* the small tube of the telescope, at one end of which is D F, a concave mirror, with a hole in the middle at P, the principal focus of

which is at I K: opposite to the hole P is a small mirror, L, concave towards the great one. It is fixed on a strong wire, M, and may, by means of a long screw on the outside of the tube, be made to move backwards or forwards: A B is a remote object, from which rays will flow to the great mirror D F.

Ja. And I see you have taken from a pencil of rays only two from the top, and two rays from the bottom.

Fa. And in order to trace the progress of the reflections and refractions, the upper rays are represented by full lines; the lower ones by dotted lines. The rays at C and E, falling upon the mirror at D and F, are reflected, and form an inverted image at *m*.

Ch. Is there anything there to receive the image?

Fa. No: and therefore they go on towards the reflector L; the rays from different parts of the object crossing one another a little before they reach L.

Ja. Does not the hole at P tend to distort the image?

Fa. Not at all: the only defect is, that there is less light. From the mirror L the rays are reflected nearly parallel through P: there they have to pass the plano-convex lens R, which causes them to converge at *a b*, and the image is now painted in the small tube near the eye.

Ch. For what purpose is the other plano-convex lens, S?

Fa. Having, by means of the lens R, and the two concave mirrors, brought the image of the object so near as at *a b*, we only want to magnify the image.

Ja. This, I see, is done by the lens S?

Fa. It is, and will appear as large as *c d;* that is, the image is seen under the angle *c f d*.

Ch. How do you estimate the magnifying power of the reflecting telescope?

Fa. The rule is this: "Multiply the focal distance of the large mirror by the distance of the small mirror from the image *m:* then multiply the focal distance of the small mirror by the focal distance of the eye-glass, and divide these two products by one another, and the quotient is the magnifying power."

Ja. It is not probable that we should know all these particulars in every instrument we may possess.

Fa. By the following method, however, you may find the same thing by experiment. "Observe at what distance you

can read any book with the naked eye, and then, removing the book to the farthest distanee at which you can distinetly read by means of the teleseopc, divide the latter by the former."

Ch. Did not Dr. Hersehel construet a very large reflecting telescope?

Fa. Yes; the tube of his large teleseope was nearly 40 feet long, and 4 feet 10 inches in diameter. The eoncave surface of the great mirror was 48 inches of polished surface in diameter, $3\frac{1}{2}$ inches thiek, weighed 2118 lbs., and magnified 6400 times. This immense instrument oeeupied four years in its construction, and was finished Aug. 28, 1789; on which day was discovered the sixth satellite of Saturn. Lately, however, a considerably larger one has been eonstructed by Lord Ross.

Ch. Are not telescopes subject to certain imperfections?

Fa. Yes: in refleeting telescopes the imperfections arise principally from the tarnishing of the metal specula employed in them, and the diffieulty of giving them the true figure; for an error in a reflecting surface affects the direction of the rays much more than a like error in a refracting surface.

In refracting teleseopes, certain of the rays of light are more refracted than others; in eonsequence of which the object appears indistinct, and eneircled by a ring of variously intermingled colours; this imperfeetion, however, after very many experiments, was remedied by the celebrated Dollond, who eonstructed object-glasses to a great nicety, and the most nearly approaching the achromatic powers of the human eye: since his time the subject of light has been so mueh studied, and the science so mueh improved, that aehromatic glasses are manufactured extensively both at home and abroad. These glasses are said to depend principally on the mixture of proper quantities of flint and other materials used in the manufaeture of glass.

Ch. What is the meaning of the term achromatie?

Fa. It is derived from the Greek, the particle *a* (α), meaning "without," and *chroma* (χρωμα), meaning "eolour;" that is, want of colour.

Ch. Why was Dr. Herschel's teleseope plaeed in the open air instead of within a building?

Fa. The reason given by a very enlightened astronomer,

Mr. Aubert, is, that the undulation of the air is greatest when the telescope is confined within a room: for the temperature of the room being seldom correspondent with that which is out of doors, there is almost always a considerable undulation produced at the window, where the streams of hot and cold air combine. For this reason, undoubtedly, Herschel preferred that situation.

Ch. What is this *undulation*, and whence does it proceed?

Fa. Exhalations arising from the earth have always an undulating or rolling motion, like the waves of the sea, or like that of steam; so that objects seen through them appear to tremble or quiver, as is evident to the naked eye when we look stedfastly at distant objects in a hot summer day.

The telescope is thought to have been invented, or rather described, by Roger Bacon, about 1250; and it appears that none were constructed till one Metius, at Alkmaer, and Jansen, of Middleburgh, made some between 1590 and 1609. The name is derived from two Greek words, *tele* (τηλε), "distant," and *scopeo* (σκοπεω), "I see."

QUESTIONS FOR EXAMINATION.

What are the peculiar advantages of a reflecting telescope? — Can you point out the construction of one by referring to fig. 36? — How is the magnifying power of the reflecting telescope estimated? — How is that done by experiment? — What is the size of Dr. Herschel's grand telescope, and how many times does it magnify?

CONVERSATION XXI.

OF THE MICROSCOPE — ITS PRINCIPLES — OF THE SINGLE MICROSCOPE — OF THE COMPOUND MICROSCOPE — OF THE SOLAR MICROSCOPE.

Father. We will now describe the microscope; which is an instrument for viewing very small objects. You know that, in general, persons who have good sight cannot distinctly view an object at a nearer distance than about six inches.

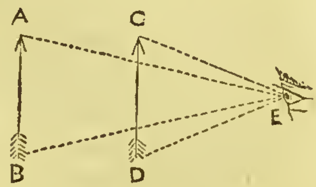
Ch. I cannot read a book at a shorter distance than that; but if I look through a small hole, made with a pin or needle in a sheet of brown paper, I can read at a very small distance indeed.

Fa. You mean, that the letters appear, in that case, very much magnified: the reason of which is, that you are able to

see at a much shorter distanee in this way than you ean without the intervention of the paper. Whatever instrument, or eontrivanee, can render minute objeets visible and distinct, is properly a mieroscope.

Ja. If I look through the hole in the paper, at the distance of five or six inehes from the print, it is not magnified.

Fa. No: the objeet must be brought near, to increase the angle by whieh it is seen. This is the principle of all mieroseopes, from the single lens to the most eompound instrument. If A B represent an arrow seen by the unaided eye, it will appear of a eertain magnitude; but if placed as at C D, it will appear nearly twice as large, being seen under nearly twice the angle, for the angle C D E is nearly twice as great as the angle A B E.



Ch. Then the hole in the card, although it produces the same effect as a lens, cannot aet in the same manner.

Fa. No. The light, on passing through it, is not affected by any refracting medium, beeause it simply passes through the air. But the hole serves the purpose of a stop or diaphragm, excluding all those lateral rays which would otherwise enter, and render the image confused.

Ch. Does the single microscope consist only of a lens?

Fa. It may consist of one or more lenses; but the object is seen through it direetly: by means of a lens, a great number of rays proceeding from an object are united in the same sensible point; and as each ray carries with it the image of the point whence it proceeded, all the rays united must form an image of the object.

Ja. Is the image *brighter* in proportion as there are more rays united?

Fa. Certainly: and it is more distinct in proportion as their natural order is preserved. In other words; a single mieroscope or lens removes the confusion that accompanies objeets when seen very near by the naked eye; and it magnifies the diameter of the object in proportion as the focal distance is less than the limit of distinct vision, whieh we may reekon from about six to eight inches.

Ch. If the foeal distance of a reading-glass be four inches, does it magnify the diameter of each letter only twiee?

Fa. Yes: but the lenses used in microscopes are often not more than $\frac{1}{4}$ or $\frac{1}{8}$ or even $\frac{1}{20}$ part of an inch in radius.

Ja. And in a double convex the focal distance is always equal to the radius of convexity.

Fa. Exactly so: now tell me how much lenses of $\frac{1}{4}$, $\frac{1}{8}$, and $\frac{1}{20}$ of an inch each, will magnify.

Ja. That is readily done, by dividing 8 inches, the limit of distinct vision, by $\frac{1}{4}$, $\frac{1}{8}$, and $\frac{1}{20}$.

Ch. And to divide a whole number, as 8, by a fraction, as $\frac{1}{4}$, &c., is to multiply that number by the denominator of the fraction: of course, 8 multiplied by 4, gives 32; that is, the lens, whose radius is a $\frac{1}{4}$ of an inch, magnifies the diameter of the object 32 times.

Ja. Therefore the lenses, of which the radii are $\frac{1}{8}$ and $\frac{1}{20}$, will magnify as 8 multiplied by 8, and 8 multiplied by 20; that is, the former will magnify 64 times, the latter 160 times the diameter of an object.

Fa. You see, then, that the smaller the lens, the greater its magnifying power. Dr. Hooke says, in his work on the microscope, that he has made lenses so small as to be able, not only to distinguish the particles of bodies a million times smaller than a visible point, but even to make those visible of which a million times a million would hardly be equal to the bulk of the smallest grain of sand.

Ch. I wonder how he made them.

Fa. I will give you his description. He first took a very narrow and thin slip of clear glass, melted it in the flame of a candle or lamp, and drew it out into exceedingly fine threads. The end of one of these threads he melted again in the flame, till it ran into a very small drop, which, when cool, he fixed in a thin plate of metal; so that the middle of it might be directly over the centre of an extremely small hole made in the plate. Here is a very convenient single microscope.

Ja. It does not seem, at first sight, so simple as those which you have just now described.

Fa. A is a circular piece of brass, (it may be made of wood, ivory, &c.) in the middle of which is a very small hole; in this is fixed a small lens, the focal distance of which is A D; at that distance is a pair of pliers, D E,

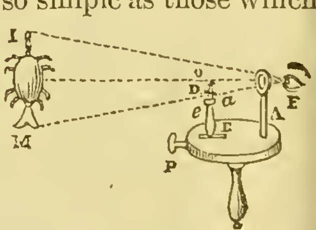


Fig. 39.

which may be adjusted by the sliding screw, and opened by means of two little studs, *a c:* with these any small object may be taken up and viewed with the eye placed in the other focus of the lens at F, to which it will appear magnified, as at I M.

Ch. I see, by the joint, that it is made to fold up.

Fa. It is: and may be put into a case, and carried about in the pocket, without any incumbrance or inconvenience. Let us now look at a double, or compound, microscope.

Ja. How many glasses are there in this?

Fa. There are two; and the construction of it may be seen by this figure: *c d* is called the object-glass, and *e f* the eye-glass. The small object, *a b*, is placed a little further from the glass *c d* than its principal focus; so that the pencils of rays flowing from the different points of the object, and passing through the glass, may be made to converge and unite in as many points between *g* and *h*, where the image of the object will be formed. This image is viewed by the eye-glass *e f*, which is so placed that the image *g h* may be in the focus, and the eye at about an equal distance on the other side: the rays of each pencil will be parallel after going out of the eye-glass, as at *e* and *f*, till they come to the eye at *k;* by the humours of which they will be converged and collected into points on the retina, and form the large inverted image A B.

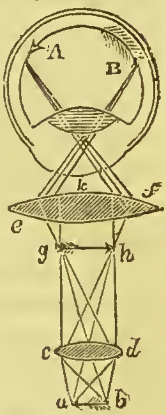


Fig. 40.

Ch. Pray, Papa, how do you calculate the magnifying power of this microscope?

Fa. There are two proportions, which, when found, are to be multiplied into one another. (1) As the distance of the image from the object-glass is *greater* than its distance from the eye-glass; and (2) as the distance from the object is *less* than the limit of distinct vision: thus—If the distance of the image from the object-glass be 4 times greater than from the eye-glass, the magnifying power of 4 is gained; and if the focal distance of the eye-glass be one inch, and the distance of distinct vision be considered as 7 inches, the magnifying power of 7 is gained, and 7 × 4 gives 28; that is, the diameter of the object will be magnified 28 times, and the surface will be magnified 784 times.

Ja. Do you mean that an object through such a microscope

will appear 784 times larger than if it were presented to the naked eye?

Fa. Yes, I do: provided the limit of distinct vision be 7 inches: but some persons, who are short-sighted, can see as distinctly at 5 or 4 inches as another can at 7 or 8. To the former the object will not appear so large as to the latter.

How much will a microscope of this kind magnify to three different persons, whose eyes are so formed as to see distinctly at the distance of 6, 7, and 8 inches by the naked eye, supposing the image of the object-glass to be five times as distant as from the eye-glass, and the focal distance of the eye-glass to be only the tenth part of an inch?

Ch. As five is gained by the distances between the glasses, and 60, 70, and 80, by the eye-glass, the magnifying powers will be as 300, 350, and 400.

Ja. How is it that 60, 70, and even 80 are gained by the eye-glass?

Ch. Because the distances of distinct vision are put at 6, 7, and 8 inches; and these are to be divided by the focal distance of the eye-glass, or by $\frac{1}{10}$; but, to divide a whole number by a fraction, we must multiply that number by the denominator, or lower figure in the fraction: therefore the power gained by the distance between the two glasses, or 5, must be multiplied by 60, 70, or 80. And the surface of the object will be magnified in proportion to the square of 300, 350, or 400, that is, as 90,000, 122,500, or 160,000.

Fa. We come now to the solar microscope, which is by far the most entertaining, because the image is much larger, and, being thrown on a sheet, or other white surface, may be viewed by many spectators at the same time, without any fatigue to the eye. Here is one fixed in the window shutter. I can, however, best explain its construction by a figure.

Ja. There is a looking-glass outside the window.

Fa. Yes; It consists of a looking-glass, s o, without, the lens *a b* in the shutter *d u*, and the lens *n m* within the dark room. These three parts are united to a brass tube,

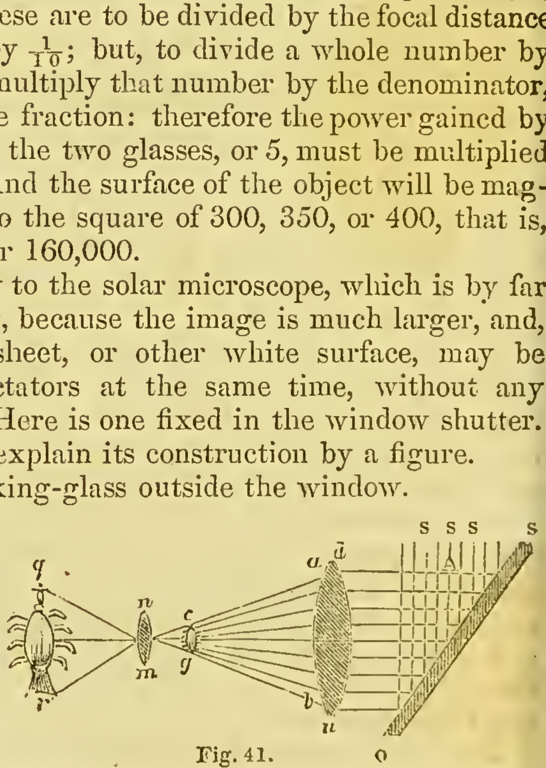


Fig. 41.

and placed within it. The looking-glass can be turned by the adjusting-screw, so as to receive the incident rays of the sun, s s s, and reflect them through the tube into the room. The lens *a b* collects those rays into a focus at *n m*, where there is another magnifier: there, of course, the rays cross, and diverge to the white screen on which the image of the object will be painted.

Ch. I see the object is placed a little behind the focus.

Fa. If it were in the focus, it would be burnt to pieces immediately. The magnifying power of this instrument depends on the distance of the sheet or white screen: about 10 feet is, perhaps, as good a distance as any. You perceive that the size of the image is to that of the object as the distance of the former from the lens *n m* is to that of the latter.

Ja. Then the nearer the object to the lens, and the further the screen from it, the greater the power of this microscope.

Fa. Certainly: and if the object be only half an inch from the lens, and the screen nine feet, the image will be 46,656 times larger than the object. Do you understand this?

Ch. Yes; the object being only half an inch from the lens, and the image 9 feet or 108 inches, or 216 half inches, the diameter of the image will be 216 times larger than the diameter of the object; and this number multiplied into itself will give 46,656.

Fa. This instrument is only calculated to exhibit transparent objects, or such as the light can pass through. For opaque objects, the other kind of microscope is used.

Ch. What is the meaning, Papa, of the word microscope?

Fa. It is derived from two Greek words, *micros* (μικρος), "small," and *scopeo* (σκοπεω), "I see." And remember that the most convex lenses, having the shortest length of parallel rays, magnify the most, as they permit the object to approach nearer the eye than those of a flatter kind.

A drop of water is a microscope: for if a small hole be made in a plate of metal or any other thin substance, and carefully filled with a drop of water, small objects may be seen through it very distinctly, and much magnified.

Ch. How are the compound portable microscopes constructed?

Fa. They are usually made to consist of an object lens, by which the image is formed, enlarged, and inverted, an am-

plifying lens, by which the field of view is enlarged; and an eye-glass or lens, by means of which the eye is allowed to approach very near, and consequently to view the image under a very great angle of apparent magnitude.

Ch. Why is it that the microscopes now sold are so expensive?

Fa. On account of the laborious accuracy required in their construction; and this falls principally upon the object-glasses. In the older microscopes, the object-glass consists of a simple lens, the image formed by which is again magnified by the eye-piece or eye-glass; whilst in the modern instruments, which have attained a surprising degree of perfection, the object-glass consists generally of at least six pieces cemented together in pairs.

Ch. Is this really necessary?

Fa. It is. I have stated to you how convex lenses bring the rays of light to a focus, and so long as convex lenses are used as simple microscopes only, this is found to be true; but when the image formed by simple lenses is magnified by an eye-glass or eye-piece, as in the compound microscope, defects become visible to such an extent, that although great magnifying power is obtained, the image is confused, and accompanied with colours which do not belong to the objects viewed.

Ch. What is the cause of this?

Fa. These defects arise from two causes: 1st, the impossibility of grinding the surfaces of the lenses to such a form that all the rays may converge to an exact focus; this imperfection is called *spherical aberration;* and 2ndly, the fact, that as, in accordance with what I have told you, the different colours of which white light consists do not possess the same degree of refrangibility, they become separated on passing through the lens, and thus give rise to coloured images: this is called *chromatic aberration* or *dispersion.*

Ch. And how are they prevented?

Fa. By constructing the lenses of which the object-glass is composed of pieces of such kinds of glass cemented together as possess different refractive and dispersive powers, whereby the error from too great refraction in one piece is compensated or corrected by the less refraction in the next. Glasses thus corrected are called achromatic.

Ch. Who discovered the method of making the object-glasses of compound microscopes achromatic?

Fa. This honour is due to Mr. Lister. It is true that the subject of achromatism had occupied the attention of many of the most profound philosophers of Europe, most of whom investigated it theoretically, but the paper of Mr. Lister, which was read before the Royal Society in 1829, made known the method of overcoming the difficulties which had hitherto existed, and laid the foundation of the perfection which they have now attained. Another immense advantage which achromatic glasses have over simple lenses, is that in consequence of the correction of the spherical and chromatic aberrations, a much larger pencil of light is allowed to pass through them, or, as it is said, they have a larger angular aperture. Hence the objects are seen much more brightly and distinctly through them.

Ch. Is any real use made of the microscope?

Fa. Most certainly. The advantages derived from it have been very great and very numerous. In addition to the vast insight it has given us into the nature of the minute structures and uses of the various parts of plants and animals; it has been applied to the detection of adulterations, and in fact to the detection of the nature of substances in general. For when the application of a few chemical tests is combined with microscopic examination, the tests being applied under the microscope, the nature of the most minute portions of any substance may be determined with certainty.

QUESTIONS FOR EXAMINATION.

For what is the microscope used?—Why do minute objects appear magnified by viewing them through a small hole?—Why is not the object magnified if you look through the hole at some inches distant from the print?—Explain this by figs. 37 and 38.—Of what does the single microscope consist?—What advantages are derived from this instrument, and why?—What is the rule for finding the magnifying power of a reading-glass?—To what extent has Dr. Hooke carried the powers of these lenses?—Describe the mode of making small lenses.—How many glasses are there in a compound microscope?—Can you explain the construction by fig. 40?—How is the magnifying power of the compound microscope calculated?—Explain the structure of the solar microscope.—Upon what does the magnifying power of this instrument depend?—For what purpose is it calculated?—Why are the modern microscopes so expensive?—What is spherical aberration?—What is chromatic aberration or dispersion?—How are these corrected in the object glasses of our present microscopes?—What is meant by achromatism?—Of what real use is the microscope?

CONVERSATION XXII.

OF THE CAMERA OBSCURA, MAGIC LANTERN AND MULTIPLYING GLASS.

Father. We shall now treat upon some miscellaneous subjects; of which the first shall be the *Camera Obscura.*

Ch. What is a camera obscura?

Fa. The meaning of the term is a darkened chamber, from two Latin words, *camera*, "a chamber," and *obscurus*, "dark." The construction of it is very simple, and will be understood in a moment by you, since you know the properties of the convex lens.

A convex lens, placed in a hole of a window-shutter, will exhibit, on a white sheet of paper placed in the focus of the glass, all the objects on the outside, (such as fields, trees, men, houses, &c.) in an inverted position.

Ja. Is the room to be quite dark, except the light which is admitted through the lens?

Fa. It ought to be so; and to produce a very interesting picture, the sun should shine upon the objects.

Ja. Is there no other kind of camera obscura?

Fa. A portable one may be made with a square box; in one side of which is to be fixed a tube, having a convex lens within it: the box contains a plane mirror, inclining backwards from the tube, at an angle of 45 degrees.

Ch. On what does this mirror reflect the image of the object?

Fa. On a square of ground glass, fixed to the top of the box: and if a piece of oiled paper be stretched on the glass, a landscape may be easily copied; or the outline may be sketched on the rough surface of the glass.

Ja. Why is the mirror to be placed exactly at an angle of 45 degrees?

Fa. The image of the object would naturally be formed at the back of the box, opposite to the lens. In order, therefore, to throw it on the top, the mirror must be so placed that the angle of incidence shall be equal to the angle of reflection. In the box, according to its usual make, the top is at right angles to the end; that is, at an angle of 90 degrees: therefore the mirror is put at half 90, or 45 degrees.

Ch. Then the incident rays, falling upon a surface which

inclines at an angle of 45 degrees, will be reflected at an equal angle of 45 degrees, which is the angle that the glass top of the box bears with respect to the mirror.

Ja. If I understand you clearly, the rays would have been reflected back on the lens, and none would have proceeded to the top of the box, if the mirror had been placed at the end of it.

Fa. Just so: in the same manner as when one person stands before a looking-glass, another at the side of the room cannot see his image in the glass, because the rays flowing from him to the looking-glass are thrown back again to himself: but if each person stands on the opposite side of the room, while the glass is in the middle at the end of it, they will both stand at an angle of 45 degrees with regard to the glass; and the rays from each will be reflected to the other.

Ch. Is the tube fixed in this machine?

Fa. No: it is made to draw out, or push in, so as to adjust the distance of the convex glass from the mirror in proportion to the distance of the outward objects, till they are distinctly painted on the horizontal glass.

The best camera obscuras are formed by placing a revolving mirror in an inclined position at the top of a building, so that the rays may be thrown down on a convex lens in the roof, and which should portray them distinctly on a table. The invention of this instrument is assigned to Baptiste Porta, in 1500; although some attribute it to Roger Bacon. By an ingenious process lately discovered by Daguerre, the images derived from the camera obscura have been most clearly and accurately fixed on metal plates; but without colour, further than degrees of shade. The process, from the inventor, has been named *Daguerreotype*, and latterly *Photogenic drawing*, or *Photography*, from the Greek *phos* (φῶς), "light," and *gignomai* (γιγνομαι), "I make, or generate;" or *grapho* (γραφω), "I write, or describe." The method pursued seems to be that of preparing first a piece of copper well plated with silver, polished and cleansed by diluted nitric acid; after which it is exposed to the vapour of iodine, which gives it a yellow colour, and upon this surface the rays of light of the object are impinged by the camera obscura. At this stage, though the surface of the plate appears completely dull and void of all images or views, the plate is subjected to the action of the vapour of mercury at an inclined position of 45°. It is next washed in a solution

of hyposulphate of soda, and then with boiling water. When dry, a perfect representation of the object is obtained.

Ch. Are not landscapes sometimes taken upon paper by the same process?

Fa. Not exactly. The agent which delineates the picture is light in both cases, but a somewhat modified proceeding is adopted in regard to the production of the sensitive coating upon which the image is impressed.

Ch. Will you describe this to me?

Fa. I will. A sheet of paper is either soaked in, or one side painted over, with a solution of nitrate of silver or common lunar caustic; it is then treated in the same manner with a solution of common salt. The paper thus prepared, is now dried in the dark, and then placed in the camera. After remaining there for a short time, it is soaked in a solution of the hyposulphite of soda, which dissolves all those portions of the salt of silver which have not been acted upon by the light. A very pretty and exact drawing is then obtained of the objects towards which the camera was directed.

Ja. Will you now explain the structure of the magic lantern, which has long afforded us so much amusement?

Fa. This little machine consists, as you know, of a sort of tin box; within it is a lamp or candle, the light of which passes through a large plano-convex lens placed in a tube fixed in front. This strongly illuminates objects painted on slips of glass, and which are placed before the lens in an inverted position. A sheet, or other white surface, is arranged so as to receive the images.

Ch. Do you invert the glasses on which the figures are drawn, in order that the images of them may be erect?

Fa. Yes: and the illumination may be greatly increased, and the effect much more powerful, by placing a concave mirror at the back of the lamp.

Ch. Did you not tell us that the *Phantasmagoria*, which we once saw at the Lyceum, was a species of magic lantern?

Fa. Yes: but there is some difference between them. In common magic lanterns, the figures are painted on transparent glass; consequently, the image on the screen is a circle of light, having one or more figures on it; but in the Phantasmagoria, all the glass is made opaque, except the figure, so that no light can come upon the screen but what passes through the figures, which are painted in transparent colours.

Ja. There was no sheet to receive the picture.

Fa. No: the representation was thrown on a thin screen of silk, placed between the spectators and the lantern.

Ch. What caused the images to appear approaching and receding?

Fa. That was effected by removing the lantern further from the screen, or bringing it nearer to it: for the size of the image must increase if the lantern be carried back, because the rays come in the shape of a cone; and as no part of the screen is visible, the figure appears to be formed in the air, and to move further off when it becomes smaller, and to come nearer as it increases.

The term Phantasmagoria is derived from two Greek words, *phantasma* (φανтασμα), "an appearance," and *agoraomai* (ἀγοραομαι), "I collect."

Ja. Here is another instrument, the construction of which you promised to explain—namely, the *multiplying glass.*

Fa. One side of this glass is cut into many distinct surfaces; and in looking at any object through it, such as your brother, you will see, not one object only, but as many as are the plane surfaces on the glass.

I will draw a figure to illustrate this. Let A *i* B represent a glass, flat at the side next the eye H, and cut into three distinct surfaces on the opposite side, as A *b*, *b* *d*, *d* B. The object C will not appear magnified, but as rays will flow from it to all parts of the glass, and each plane surface will refract these rays to the eye, the same object will appear to the eye in the direction of the rays, which enter it through each surface. Thus a ray, C *i*, falling perpendicularly on the middle surface, will suffer no refraction, but show the object in its true place at C: the ray from C *b* falling obliquely on the plane surface A *b*, will be refracted in the direction *b* *e*, and, on leaving the glass at *e*, it will pass to the eye in the direction *e* H; and therefore it appears at E: the ray C *d* will, for the same reason, be refracted to the eye in the direction D H, and the object C will appear also in D.

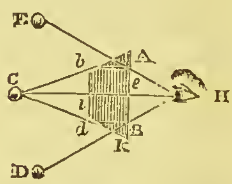


Fig. 42.

If, instead of three sides, the glass had been cut into 6 or 20, there would have appeared 6 or 20 different objects, differently situated.

QUESTIONS FOR EXAMINATION.

Can you describe the structure and uses of a camera obscura? — What things are necessary to obtain an interesting picture? — How is the portable camera obscura constructed? — Of what does the magic lantern consist? — How are the figures placed for the images to be erect? — In what does the magic lantern differ from the phantasmagoria? — In the latter the images appear sometimes to be receding and at others approaching; what is the cause of this? — Illustrate the nature of the multiplying-glass by fig. 42.

SOME OF THE LEADING DEFINITIONS IN OPTICS, WHICH IT IS RECOMMENDED THAT THE PUPIL SHOULD COMMIT TO MEMORY.

OPTICS.

1. Light is supposed to consist of inconceivably small particles, radiating from a luminous body.

2. Light proceeds in straight lines from the luminous body. It travels at the rate of about 200,000 miles in a second of time.

3. The intensity of light decreases as the square of the distance from the luminous body increases.

4. When light strikes obliquely upon a surface, it is so reflected, that the angle of reflection is equal to the angle of incidence.

5. The properties of mirrors depend on reflected light.

6. Whatever suffers the rays of light to pass through it is called a medium.

7. All transparent fluids are called media; and the more transparent the body, the more perfect is the medium.

8. When rays of light are bent out of their course on entering a denser or rarer medium, they are said to be refracted.

9. When light passes out of a rarer into a denser medium, it is drawn towards the perpendicular.

10. When light passes from a rarer to a denser medium, it moves in a direction farther from the perpendicular.

11. We see everything in the direction of that line in which the rays approach us last.

12. Refraction takes place in all kinds of glass; but in glass that is thin it is generally overlooked.

13. The image of an object seen in water always appears higher than the object really is.

14. We cannot judge of distances or of magnitudes so well in water as in air.

15. By means of refraction the sun is seen every clear morning several minutes before he comes to the horizon, and as long, after he sinks beneath it in the evening.

16. The sun is never seen in that place in the heavens that he appears to be.

17. A pencil of rays is any number that proceed from a point.

18. Parallel rays are such as move always at the same distance from each other.

19. A lens is a glass ground into a certain form to collect or disperse the rays of light.

20. The force of the heat collected in the focus is in proportion to the common heat of the sun as the area of the glass is to the area of the focus.

21. As an object approaches a convex lens, its image departs from it.

22. Convex lenses collect the rays of light, or make them converge to a focus.

23. Concave lenses disperse the rays of light.

24. The focus of a double convex lens is at the distance of the radius of convexity: and so is the imaginary focus of the double concave lens.

25. The focus of the plane convex is at the distance of the diameter of the convexity.

26. The images of objects placed beyond the focus of a convex lens are inverted, and real.

27. Light is composed of seven colours.

28. The rainbow is owing to the separation of the rays of light into its primitive colours, by the drops of falling rain.

29. All colours are supposed to exist only in the light of luminous bodies.

30. We judge of the colour of objects from the reflected rays.

31. The whiteness of paper is occasioned by its reflecting the greatest part of all the rays that fall upon it.

32. Many transparent media reflect one colour and transmit another.

33. In all mirrors the angle of reflection is equal to the angle of incidence.

34. In a concave mirror the image is less than the object, when the object is more remote from the mirror than the centre of concavity, and the image is between the object and mirror.

35. If the object is in the centre, then the image and object will coincide:—if nearer the glass than the centre, the image will be more remote, and larger than the object.

36. The image formed by a concave mirror is always before it, except when the object is nearer the mirror than the principal focus.

37. The human eye is an optical instrument, consisting of three coats and three humours.

38. The humours of the eye refract the rays of light like glass lenses.

39. The retina receives the images of objects produced by refraction.

40. The optic nerve conveys to the brain the sensations produced on the retina.

41. Spectacles are intended to alter the direction of the rays of light and bring them to a proper degree of convergency.

42. Convex glasses are used when the eyes are too flat, and concave glasses are used when they are too round.

43. There are generally two rainbows seen at the same ime. The bright one is produced by one reflection and two refractions: the faint one is occasioned by two reflections and two refractions.

44. There are two kinds of telescopes, the refracting and the reflecting: the former depends on lenses for its operation, the latter chiefly upon mirrors.

45. Refracting telescopes are used principally for viewing terrestrial objects: but the reflecting telescope is used for astronomical purposes.

46. Telescopes in general represent objects to be nearer, not larger.

47. Achromatic telescopes are such as have the glasses so contrived as to correct the unequal refraction of the rays of light.

48. Microscopes are instruments for viewing very small objects. They apparently magnify objects, because they enable us to see them nearer without destroying the distinctness of vision.

49. The single microscope consists of only one lens.

50. The camera obscura is contrived to exhibit, in a room, a picture of a landscape or other objects without.

51. The magic lantern is a small machine intended for the amusement of young persons, by magnifying paintings on glass and throwing their images on a white screen in a darkened room.

52. The phantasmagoria is a kind of magic lantern, which causes the images to be thrown upon a thin screen of silk placed between the lantern and spectator.

MAGNETISM.

FIRST CONVERSATION.

OF THE MAGNET AND ITS PROPERTIES.

FATHER—CHARLES—JAMES.

Father. You see this dark mineral body: it is one of the oxides of iron; and you know it has the property of attracting needles and other small iron substances.

Ja. Yes; it is called a loadstone, leading-stone, or magnet. We have often been amused with it; but you told us that it possessed a much more important property than that of attracting iron and steel.

Fa. This is what is called the *directive property*, by which mariners are enabled to conduct their vessels through the mighty ocean when out of sight of land. By the aid of this miners also are guided in their subterranean inquiries, and the traveller through deserts otherwise impassable.

Ch. Were not mariners unable to make long and very distant voyages, before this property of the magnet was discovered?

Fa. Yes: then they contented themselves with mere coasting voyages; seldom trusting themselves from the sight of land.

Ja. How long is it since this great discovery was first made?

Fa. Upwards of five hundred years: but it is not possible to ascertain, with any degree of precision, to whom we are indebted for it; yet Roger Bacon appears to have discovered its property of pointing to the north.

Ch. You have not told us in what the discovery consists.

Fa. When a magnet, or a needle rubbed with a magnet, is freely suspended, it will always, and in all places, stand nearly North and South.

Ch. Is it known which end points to the North, and which to the South?

Fa. Yes: or it would be of little use: each magnet and each needle, or other piece of iron, that is made an *artificial* magnet by being properly rubbed with the *natural* magnet, has a North end and a South end, called the *North* and *South poles;* to the former a mark is placed, for the purpose of distinguishing it.

Ja. Then if a ship were to make a voyage to the North, it must follow the direction which the magnet takes.

Fa. Yes: and if it were bound a westerly course, the needle always pointing North, the ship must keep in a direction at right angles to the needle. In other words, the direction of the needle must be across the *ship.*

Ch. Could not the same object be obtained by means of the Pole Star?

Fa. It might, in a considerable degree, provided you could always insure a fine clear sky. But what could be done in cloudy weather, which in some latitudes lasts for many days together?

Ch. I did not think of that.

Fa. Without the use of the magnet, no persons could have ventured upon such voyages as those to the West Indies and other distant parts: the knowledge, therefore, of this instrument cannot be too highly prized.

Ja. Is that a magnet which is fixed to the bottom of the globe, and by means of which we set the globe in a proper direction with regard to the cardinal points, North, South, East, and West?

Fa. This is called a Compass, the needle of which, being rubbed by the natural or real magnet, becomes possessed of the same properties as those which belong to the magnet itself.

Ch. Can any iron and steel be made magnetic?

Fa. They can: bars of iron thus prepared are called *artificial magnets.*

Ja. Will these soon lose the properties thus obtained?

Fa. Artificial magnets will retain their properties almost any length of time; and, since they may be rendered more powerful than natural ones, and can be made of any form,

they are generally used; so that the natural magnet is kept as a curiosity.

Ch. What are the leading properties of the magnet?

Fa. (1.) A magnet attracts iron. (2.) When placed so as to be at liberty to move in any direction, its north end points to the north pole, and its south end to the south pole: that is called the *polarity* of the magnet. (3.) When the *north* pole of one magnet is presented to the *south* pole of another, they will attract one another. But if the two *south*, or the two *north* poles are presented to each other, they will repel. (4.) When a magnet is so situated as to be at liberty to move any way, its two poles do not lie in an horizontal direction: it inclines one of its poles towards the horizon, and, of course, raises the other pole above it: this is called the *inclination* or *dip* of the magnet. (5.) Any magnet may be made to impart its properties to iron and steel.

QUESTIONS FOR EXAMINATION

What is the principal property of the magnet? — How were voyages made before the magnet and its properties were known? — When was it discovered? — In what does the directive power consist? — How are the north and south poles of a magnet distinguished? — In what way would a mariner be directed by the magnet, if he wished to sail from any port in a direction due west?— Would not the pole star be sufficient for the guidance of ships? — What is a compass?—What do you mean by artificial magnets?— Tell me what are the leading properties of the magnet.

CONVERSATION II.

MAGNETIC ATTRACTION AND REPULSION.

Father. Having mentioned the several properties of the magnet or loadstone, I intend, at this time, to enter more particularly into the nature of magnetic attraction and repulsion.—Here is a thin iron bar, eight or nine inches long, rendered magnetic, and on that account it is now called an artificial magnet. I bring a small piece of iron within a little distance of one of the poles of the magnet, and you see it is attracted or drawn to it.

Ch. Will not the same effect be produced if the iron be presented to any other part of the magnet?

Fa. The attraction is strongest at the poles, and it diminishes in proportion to the distance; so that in the middle,

between the poles, there is no attraction, as you shall see by means of this large needle.

Ja. When you held the needle near the pole of the magnet, the magnet moved to the needle; which looks as if the needle attracted the magnet.

Fa. So it does. The attraction is mutual, as is evident from the following experiment. I place the small magnet on a piece of cork, and the needle on another piece. Now let them float on water, at a little distance from each other, and you will observe that the magnet moves towards the iron as much as the iron moves towards the magnet.

Ch. If two magnets were put in this situation, what would be the effect produced?

Fa. If poles of the same name (that is, the two north, or the two south) be brought near together, they will repel one another; but if a north and a south be presented, the same kind of attraction as there was between the magnet and needle will be visible.

Ja. Will there be any attraction or repulsion if other bodies, such as paper, or thin slips of wood, be placed between the magnets, or between the magnet and iron?

Fa. Neither the magnetic attraction nor repulsion is in the least diminished, or in any way affected by the interposition of any kind of bodies, except iron. Bring the magnets together within the attracting or repelling distance, and hold a slip of wood between them, they both come to the wood, as you see.

Ch. You said that iron was more easily rendered magnetic than steel. Does it retain the properties as long too?

Fa. If a piece of soft iron and a piece of hard steel be brought within the influence of a magnet, the iron will be most forcibly attracted; but it will almost instantly lose its acquired magnetism, whereas the hard steel will preserve it a long time.

Ja. Are magnetic attraction and repulsion at all like what we have sometimes seen in electricity?

Fa. In some instances there is a great similarity. For example (1.) I tie two pieces of soft wire, each to a separate thread, which join at the top, and let them hang freely from a hook, x. If I bring the north end of a magnetic bar just under them, you

Fig. 1.

will see the wires repel one another, as shown in the figure hanging from *z*.

Ch. Is that occasioned by the repelling power which both wires have acquired in consequence of being both rendered magnetic with the same pole?

Fa. It is: and the same thing would have occurred if the south pole had been presented instead of the north.

Ja. Will they remain long in that position?

Fa. If the wires are of very soft iron. they will quickly lose their magnetic power; but if steel wires be used, such as common sewing needles, they will continue to repel each other after the removal of the magnet.

Again: I lay a sheet of paper flat upon a table, and strew some iron filings upon it. I now lay this small magnet amongst them, and give the table a few gentle knocks, so as to shake the filings; observe now in what manner they have arranged themselves about the magnet.

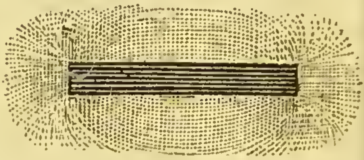


Fig. 2.

Ch. At the two ends, or poles, the particles of iron arrange themselves into lines, a little sideways they bend, and then form complete arches, reaching from some point in the northern half of the magnet to some other point in the southern half. How do you account for this?

Fa. Each of the particles of iron, by being brought within the sphere of the magnetic influence, becomes itself magnetic, and possessed of two poles and consequently disposes itself in the same manner as any other magnet would do, and also attracts with its extremities the contrary poles of other particles.

Again: If I shake some iron filings through a gauze sieve, upon a paper that covers a bar magnet, the filings will become magnets, and will be arranged in beautiful curves.

Ja. Does the polarity of the magnet reside only in its two ends?

Fa. No: one half of the magnet is possessed of one kind of polarity, and the other of the other kind; but the ends, or poles, are those points in which that power is the strongest; remember that — "a line drawn from one pole to the other is called the axis of the magnet."

QUESTIONS FOR EXAMINATION.

In what parts of the magnet is the attraction the strongest? — Does the needle attract the magnet, as well as the magnet attract the needle?— What experiment will prove this? — Do poles of the same name attract each other? — Is the magnetic attraction destroyed or diminished by the interposition of other bodies? — Does iron or steel retain the magnetic power the longest? — Explain the nature of magnetic attraction by fig. 1. — To what does fig. 2 refer? — What is the axis of the magnet?

CONVERSATION III.

THE METHOD OF MAKING MAGNETS—THE MARINER'S COMPASS.

Father. I have already told you that artificial magnets, which are made of steel, are now generally used in preference to the real magnet, because they can be procured with greater ease, may be varied in their form more easily, and will communicate the magnetic virtue more powerfully.

Ch. How are they made?

Fa. The best method of making artificial magnets is, to apply one or more powerful magnets to pieces of hard steel, taking care to apply the north pole of the magnet or magnets to that extremity of the steel which is required to be made the south pole, and to apply the south pole of the magnet to the opposite extremity of the piece of steel.

Ja. Does a magnet, by communicating its properties to other bodies, diminish its own power?

Fa. No: it is even increased by it.—A bar of iron, three or four feet long, kept some time in a vertical position, will become magnetic; the lower extremity of it attracting the south-pole, and repelling the north-pole. But if the bar be inverted, the polarity will be reversed.

Ch. Will steel produce the same effects?

Fa. It will not. The iron must be soft, and hence bars of iron, that have been long in a perpendicular position, are generally found to be magnetic, as fire-irons, bars of windows, &c. If a long piece of hard iron be made red-hot, and then left to cool in the direction of the magnetic line, it usually becomes magnetic.

Striking an iron-bar with a hammer, or rubbing it with a file, while held in this direction, renders it magnetic. An electric shock, and lightning, frequently render iron magnetic.

Ja. An artificial magnet, you say, is often more powerful than the real one. Can a magnet, therefore, communicate to steel a stronger power than it possesses?

Fa. Certainly not: but two or more magnets, joined together, may communicate a greater power to a piece of steel than either of them possesses singly.

Ch. Then you gain power according to the number of magnets made use of?

Fa. Yes: very powerful magnets may be formed by first constructing several weak magnets, and then joining them together to form a compound one, and to act more powerfully upon a piece of steel.

The following methods are among the best for forming artificial magnets:—

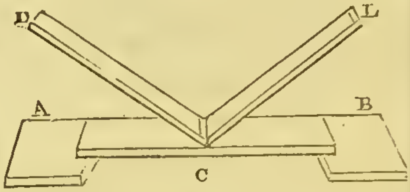


Fig. 3.

1. Place two magnetic bars, A and B, in a line, so that the north or marked end of one shall be opposite to the south end of the other, but at such a distance that the magnet C, to be touched, may rest with its marked end on the unmarked end of B, and its unmarked end on the marked end of A. Now apply the north end of the magnet L, and the south end of D, to the middle of C, the opposite ends being elevated as in the figure. Draw L and D asunder along the bar C; one towards A, the other towards B; preserving the same elevation: remove L D a foot or more from the bar when they are off the ends, then bring the north and south poles of these magnets together, and apply them again to the middle of the bar C as before: the same process is to be repeated five or six times; then turn the bar, and touch the other three sides in the same way, and, with care, the bar will acquire a strong fixed magnetism.

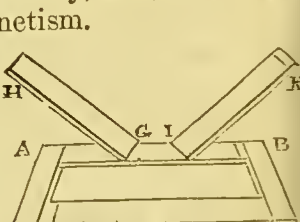


Fig. 4.

2. Upon a similar principle, two bars, A B, C D, may be rendered magnetic. These are supported by two bars of iron; and they are so placed that the marked end, B, may be opposite to the unmarked end, D: then place the two attracting poles, G I, on the middle of A B, as in the figure, moving them slowly

over it several times. The same operation is to be performed on C D, having first changed the poles of the bars, and then on the other faces of the bars; and the effect is accomplished.

The touch thus communicated may be further increased by rubbing the different faces of the bars with sets of magnetic bars, disposed as in fig. 5.

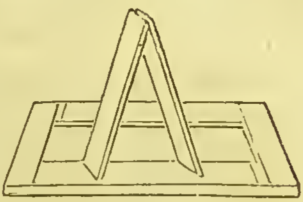


Fig. 5.

Ja. I suppose all the bars should be very smooth?

Fa. Yes; they should be well polished, the sides and ends made quite flat, and the angles exactly square.

There are many magnets made in the shape of horse-shoes: these are called horse-shoe magnets, and they retain their power very long by applying a piece of iron to the ends when not employed.

Ch. Does that prevent the power from escaping?

Fa. It seems so: the power of a magnet is even increased by allowing a piece of iron to remain attached to one or both of its poles. Of course, a single magnet should always be thus left.

Ja. How is magnetism communicated to compass-needles?

Fa. Fasten the needle down on a board, and draw magnets, about six inches long, in each hand, from the centre of the needle outwards: then raise the bars to a considerable distance from the needle, bring them perpendicularly down on its centre, and draw them over again, repeating this operation about twenty times, and the ends of the needle will point to the poles contrary to those that touched them.

Ch. I remember seeing a compass when I was on board a frigate lying off Worthing; the needle of which was in a box, with a glass over it.

Fa. That was a mariner's compass, which consists of the box, the card or fly, and the needle. The box is circular, and is so suspended as to retain its horizontal position in all the motions of the ship. The glass is intended to prevent any motion of the card by the wind: the card or fly moves with the needle, which is very nicely balanced on a centre. It may, however, be noticed, that a needle which is accurately balanced before it is magnetized will lose its balance by being magnetized, on account of what is called the *dip*; therefore a

small weight, or moveable piece of brass, is placed on one side of the needle; by the regulating of which the needle will always be balanced.

QUESTIONS FOR EXAMINATION.

Why are artificial magnets generally used in preference to the real magnet? — Can you describe the method of making magnets? — By communicating its properties to other bodies, is the power of the magnet diminished? — Do iron bars in any position ever become magnetic? — What is the reason that an artificial magnet is more powerful than a real one? — Can you, by means of the figures 3, 4, and 5, describe the methods made use of in forming magnets? — What advantage is there attaching to the horse-shoe magnet? — In what manner is magnetism communicated to compass needles? — Of what does the mariner's compass consist?

CONVERSATION IV.

OF THE VARIATION OF THE COMPASS.

Charles. You said, I think, that the magnet pointed *nearly* North and South. How much does it differ from that direction?

Fa. It rarely points exactly North and South; and the *deviation* from that line is called the *variation of the compass;* which is said to be East or West.

Ja. Does this vary at different times?

Fa. It does: and the variation is very different in different parts of the world. The variation is not the same now as it was half a century ago; nor is it the same now at London as it is at Bengal or Kamtschatka. The needle is continually but slowly verging towards the East and West.

This subject was first examined by Mr. Burrowes, about the year 1580, and he found the variation then, at London, about 11° 11′ East. In the year 1657 the needle pointed due North and South: since which the variation has been gradually increasing towards the West; and in the year 1803 it was equal to something more than 24° West, and then advancing towards the same quarter.

Ch. That is at the rate of something more than ten minutes each year.

Fa. It is; but the annual variation is not regular: it is

more one year than another. It is different in the several months, and even in the hours of the day.

Ja. Therefore, if I want to set a globe due North and South, to observe the stars, I must move it till the needle in the compass points to 24° West.

Fa. Just so: and mariners knowing this, are as well able to sail by the compass as if it pointed due North.

Ch. You mentioned the property which the needle had of *dipping*, after the magnetic fluid was communicated to it. Is that always the same?

Fa. It probably is, at the same place. It was discovered by Robert Norman, a compass-maker, in the year 1576; and he then found it to dip nearly 72°; and, from many observations made at the Royal Society, it is found to be the same.

Ja. Does it differ in different places ?

Fa. Yes: in the year 1773 observations were made on the subject, in a voyage toward the north pole, and from these it appears that

In latitude	60°	18′	the dip was	75°	0′
„ „	70	45	„ „	77	52
„ „	80	12	„ „	81	52
„ „	80	27	„ „	82	2½

I will show you an experiment on this subject. Here is a magnetic bar and a small dipping needle: if I carry the needle suspended freely on a pivot, from one end of the magnetic bar to the other, it will, when directly over the south pole, settle directly perpendicularly to it, the north end being next to the south pole: as the needle is moved, the dip grows less and less, and when it comes to the magnetic centre, it will be parallel to the bar; afterwards the south end of the needle will dip, and when it comes directly over the north pole, it will be again perpendicular to the bar.

Ch. In what part of the world is the loadstone found, Papa?

Fa. Nearly in all parts; but particularly in Sweden and Norway; in China, Arabia, in the Isle of Elba, and in the Philippine Isles.

Ja. Does it act more powerfully in its natural or in its artificial state?

Fa. Its magnetism may be concentrated, as it were, and made to act more powerfully by means of artificial magnets,

which, as we have before observed, are produced by impregnating steel bars with the magnetic power, so that the natural magnets are now of little value, except as articles of curiosity.

The following facts are deserving of recollection:—

1. Every magnet has two opposite points, called *poles.*

2. A magnet, freely suspended, arranges itself so that these poles point nearly North and South. This is called the *directive property,* or polarity of the magnet.

3. When two magnets approach each other, the poles of the *same names* (that is, both North or both South) repel each other.

4. Poles of different names attract each other.

5. The loadstone is an iron ore naturally possessing magnetism.

6. Magnetism may be communicated to iron and steel.

7. A steel needle rendered magnetic, and fitted up in a box, so as to move freely in any direction, constitutes the mariner's compass.

Ch. I think there is a similarity between electricity and magnetism.

Fa. There is a considerable analogy, and a remarkable difference also between magnetism and electricity.

Electricity is of two sorts, positive and negative; bodies possessed of the same kind of electricity repel each other, and those possessed of different kinds attract each other. — In Magnetism, every magnet has two poles: poles of the same name repel each other, and the contrary poles attract each other.

In Electricity, when a body, in its natural state, is brought near to one that is electrified, it acquires a contrary electricity, and becomes attracted by it. — In Magnetism, when an iron substance is brought near one pole of a magnet, it acquires a contrary polarity, and becomes attracted by it.

One sort of electricity cannot be produced by itself. — In like manner, no body can have only one magnetic pole.

The electric fluid may be retained by electrics; but it pervades conducting substances. — The magnetic fluid is retained by iron; but it pervades all other bodies.

Magnets attract only iron; but the electric fluid attracts bodies of every sort.

The electric virtue resides on the surface of electrified bodies; but the magnetic is internal.

A magnet loses nothing of its power by magnetizing bodies; but an electrified body loses part of its electricity by electrifying other bodies.

QUESTIONS FOR EXAMINATION.

What is meant by the variation of the compass? — Is this different at different times and places? — How is a globe, having a compass attached to it, to be set due north and south? — What is meant by the dipping of the needle? — Does this vary in different places? — What experiment shows this property? Do you recollect in what particulars electricity and magnetism agree? — In what particulars do the magnetic and electric powers differ?

SOME OF THE LEADING DEFINITIONS OF MAGNETISM, WHICH IT IS RECOMMENDED THAT THE PUPIL SHOULD COMMIT TO MEMORY.

1. The magnet is a mineral body of a dark brown colour, and has the property of attracting needles and other small iron substances.
2. The cause of magnetism is unknown.
3. The directive property of the magnet is that by which mariners are able to conduct their vessels through the seas.
4. The magnet, or a needle rubbed with a magnet and freely suspended, always points nearly north and south.
5. Every magnet has two poles.
6. Iron and steel can be rendered magnetic; and bars thus prepared are called artificial magnets.
7. When two magnets are brought near each other, their poles of the same name repel each other; but poles of different names attract each other.
8. The attraction is strongest at the poles, and it diminishes in proportion to the distance of any part from the poles.
9. The attraction between the magnet and iron is mutual.
10. Magnetic attraction is not diminished, or in any way affected by the interposition of any kind of bodies, except iron.
11. The earth itself is supposed to be a great magnet, having its poles near to, but not coinciding with, the ends of the imaginary axis on which it turns.
12. The magnet, by communicating its properties to other bodies, has not its own power diminished.
13. The magnet rarely points due north and south, and its deviation from that line is called the variation of the compass.
14. The variation of the compass is different in different parts of the world, at different periods of time, and even at different hours of the day.
15. The dip of the needle was discovered by Robert Norman: in this country it is reckoned about 72°.
16. Pure iron most easily receives and loses magnetism.
17. Steel, or iron combined with carbon, retains the magnetic properties when communicated to it.

ELECTRICITY.

FIRST CONVERSATION

INTRODUCTION — THE EARLY HISTORY OF ELECTRICITY.

FATHER — CHARLES — JAMES.

Father. If I rub briskly this stick of sealing-wax on my coat-sleeve, or on a piece of dry flannel, and then hold it within an inch of any small light substanee, such as feathers, or little pieces of paper, the wax will attract them, and they will spring up and adhere to it.

Ch. I think I have heard you say that this is the effect of electricity, but I know not what eleetricity is.

Fa. Nor can I tell you its precise nature; it is, however, considered a fluid; and as it is known only by its effects, like many other agents in natural scienees, I have not hitherto attempted to bewilder your minds with useless theories, neither shall I, in the present ease, attempt to say what the electric fluid is: its action is well known: it seems diffused over every portion of matter with which we are acquainted, and, by the use of proper means, it is as easily collected from surrounding bodies, as water is taken from a river.

Ja. I see no fluid attached to the sealing-wax when you have rubbed it.

Fa. Nor do you see the air which you breathe, and with whieh you are surrounded; yet it has been proved to you that it is a fluid, and may be taken from any vessel, as certainly, though not with so much ease, as water may be poured from a glass. With the exercise of a little patience, you shall see such experiments as will not fail to convince you that there is as certainly a fluid, which is called the electric fluid, as there are such fluids as water and air.

Ch. Water must have been known ever since the creation; and the existence of the air could not long remain a secret. But who discovered the electric fluid, which is not at all evident to the sense, either of sight or feeling?

Fa. Thales, who lived six centuries before the Christian era, was the first who observed the electrical properties of *amber;* and he was so struck with the appearances, that he supposed it to be animated.

It is from this circumstance of *amber* being the first substance which exhibited this peculiar property, that the science was called *electricity*, being derived from the Greek word *electron* (ἤλεκτρον), "amber."

Ja. Does amber, like sealing-wax, attract light bodies?

Fa. Yes: and there are many other substances, as well as those, that have the same power. After Thales, the first person we read of who noticed this subject, was Theophrastus. He discovered that *tourmaline* has the power of attracting light bodies. It does not, however, appear that the subject, though so extraordinary, excited much attention till A.D. 1600, when Dr. Gilbert, an English physician, examined a great variety of substances, with a view of ascertaining how far they might or might not be ranked among *electrics.*

Ch. What is meant by *electrics?*

Fa. Any substance, being excited or rubbed by the hand, or by a woollen cloth, or other means, having the power of attracting light bodies, is called an *electric.*

Ja. Is not electricity accompanied by a peculiar kind of light, and with sparks?

Fa. It is: of which we shall speak more at large hereafter. The celebrated Mr. Boyle is supposed to have been one of the first persons who obtained a glimpse of the electrical light, or who seems to have noticed it, by rubbing a diamond in the dark. But he little imagined, at that time, what astonishing effects would afterwards be produced by the same power. Sir Isaac Newton was the first who observed that excited glass attracted light bodies on the side opposite to that on which it was rubbed.

Ch. How did he make the discovery?

Fa. Having laid upon the table a round piece of glass, about two inches broad, in a brass ring, by which it was raised from the table about the eighth of an inch, and then

rubbing the glass, some little bits of paper, which were under it, were attracted by it, and moved very nimbly to and from the glass.

Ch. I remember standing by a glazier when he was cementing; that is, rubbing over some window-lights with oil, and cleaning it off with a stiff brush and whiting; and the little pieces of whiting under the glass kept continually leaping up and down, as the brush moved over the glass.

Fa. That was, undoubtedly, an electrical appearance; but I do not remember having ever seen it noticed by any writer on electricity. To-morrow we shall enter into the practical part of the subject; and I doubt not that the experiments in this part of science will be as interesting as those in any other which you have been studying. The electric light, exhibited in different forms; the various signs of attraction and repulsion acting on all bodies; the electric shock, and the discharge of the battery; will give you pleasure, and excite your admiration.

The electric shock was discovered at Leyden, in 1745, hence the name "Leyden phial;" the first discovery of the calorific properties of the electric fluid, and that it would fire spirits, was made in 1756.

QUESTIONS FOR EXAMINATION.

Mention some instances of electrical attraction. — Is the electric fluid generally diffused and readily collected? — Who discovered the electric fluid, and on what bodies was it first observed? — When did it first excite attention? — What is meant by an electric? — Who was the first person that saw the electric light? — What discovery did Sir I. Newton make on this subject? — To what is that analogous?

CONVERSATION II.

OF ELECTRIC ATTRACTION AND REPULSION—ELECTRICS AND CONDUCTORS.

Father. You must take it for granted for a little time (that is, till we exhibit before you experiments to prove it) that the earth, and all bodies with which we are acquainted, contain a certain quantity of an exceedingly elastic and penetrating fluid, which philosophers call the electric fluid.

Ch. You say a certain quantity. Is it limited?

Fa. Like other bodies, it undoubtedly has its limits. This glass will hold a certain quantity of water; but if I attempt to pour into it more than that quantity, a part will flow over. So it is with the electric fluid: there is a certain quantity which belongs to all bodies; and this is called their natural quantity; and so long as a body contains neither more nor less than this quantity, no sensible effect is produced.

Ja. Has this table any electricity in it?

Fa. Yes; and so has the ink-stand, and everything else in the room; and if I were to take proper means to put more into it than it now has, and you were to put your knuckle to it, it would throw it out in the shape of sparks.

Ja. I should like to see this done.

Ch. But what would happen if you should take away some of its natural quantity?

Fa. Why, then, if you presented any part of your body to the table, as your knuckle, a spark would go from you to the table, to supply, in some measure, the deficiency.

Ja. But, perhaps, Charles might not have more than his natural share; and in that case he could not spare any.

Fa. True: but to provide for this, the earth on which he stands would lend him a little to make up for the quantity he parted with to the table.

Ja. This must be an amusing study. I think I shall like it better than any of the others.

Fa. Take care that you do not pay for the amusement before we have done.

Here is a glass tube, about eighteen inches long, and perhaps an inch or more in diameter. I will rub it up and down quickly on my arm, the cloth on which is dry and warm; now you will see that if I present it to these fragments of paper, feather, thread, or gold-leaf, they will all move to it. That is called electrical *attraction.*

Ch. They spring back again now; and now they return to the glass.

Fa. They are, in fact, alternately attracted and repelled; and this will last several minutes if the glass be strongly excited. But there are always two states of electricity co-existent; thus when glass is rubbed on woollen cloth, the glass *attracts* and the cloth *repels;* the former is called *positive* electricity, and the latter *negative* electricity; so also, when

light bodies are attracted by excited glass, they are repelled by excited sealing-wax, and contrarywise; whence the two are said to be in opposite electric states; which gives rise to the terms *vitreous* electricity, which answers to the positive, and *resinous* electricity, which answers to the negative. I will rub the glass again. Present your knuckle to it in several parts, one after another.

Ja. What is that snapping? I feel something like the pricking of a pin.

Fa. The snapping is occasioned by little sparks which come from the tube to your knuckle; and these give the sensation of pain.

We will go into a dark room and repeat the experiment.

Ch. The sparks are evident enough now; but I do not know where they can come from.

Fa. The air and everything is full of the fluid which appears in the shape of sparks; and whatever be the cause, which I do not attempt to explain, the rubbing of the glass with the hand collects it; and having now more than its natural share, it parts with it to you, or to me, or to any one else who may be near enough to receive it.

Ja. Will any other substance, besides the coat-sleeve on your arm, or the hand, excite the tube?

Fa. Yes, many others; but flannel or woollen cloth are the best; these are called the rubbers. The glass tube, or whatever is capable of being thus excited, is called the *electric.*

Ch. Are not all sorts of solid substances susceptible of excitation?

Fa. You may rub this poker, or the round ruler for ever, without obtaining an electric spark from them.

Ja. But you said one might get a spark from the mahogany table, if it had more than its share.

Fa. So I say you may have sparks from the poker or ruler, if they possess more than their common share of the electric fluid.

Ch. How do you distinguish between bodies that can be, and those that cannot be, excited?

Fa. The *former*, as I have told you, are called *electrics* or *non-conductors*, as the glass tube; the latter, such as the poker, the ruler, your body, and a thousand other substances, are denominated *conductors.*

Ch. I should be glad to know the reason of the distinction, because I shall be more likely to remember it.

Fa. When you held your knuckle to the glass tube, you had several sparks from the different parts of it: but if I, by any means, overcharged a conductor, such as this poker, all the electricity would come away at a single spark; because the superabundant quantity flows instantaneously from every part to that point where it has an opportunity of escaping. I will illustrate this by an experiment.

Ja. Do you call the glass tube a *non-conductor* because it does not suffer the electric fluid to pass from one part of it to another?

Fa. I do. Silk, if dry, is a non-conductor. With this skein of sewing-silk I will hang the poker, or any other metal substance, A, to a hook in the ceiling, or on the back of a chair, so as to be about twelve inches from it: underneath, and near the extremity, are some small substances, as bits of paper, &c. I will excite the glass tube and present it to the upper part of the poker.

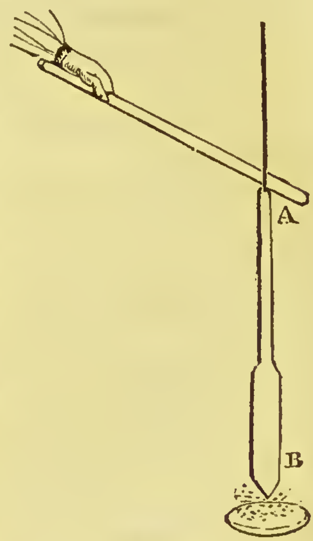


Fig. 1.

Ch. They are all attracted: but now you take away the glass they are quiet.

Fa. It is evident that the electric fluid passed from one part of the tube through the poker, which is a conductor, to the paper, and attracted it. If the glass be properly excited, you may take sparks from the poker.

Ja. Would not the same happen, if another glass tube were placed instead of the poker?

Fa. You shall try.—Now I have put the glass in the place of the poker. Let me excite the other tube as much as I will, no effect can be produced on the paper; there are no signs of electrical attraction; which shows that the electric fluid will not pass through glass.

Ch. What would have happened if any conducting substance had been used, instead of silk, to suspend the iron poker?

Fa. If I had suspended the poker with a moistened hempen

string, the electric fluid would all have passed away through it; and there would have been no appearances of electricity at the end of the poker, or, if any, they would have been very trifling.

You may vary these experiments till you make yourselves perfect with regard to the distinction between conductors and non-conductors. Sealing-wax is a non-conductor, and may be excited as the glass tube so as to produce similar effects. I will give you a list of *conductors* and *non-conductors*, disposed according to the order of their perfection; beginning in each list with the most perfect of their class: thus, glass is a better *non-conductor* or *electric* than amber; and gold a better *conductor* than silver:—

TABLE.

NON-CONDUCTORS.	CONDUCTORS.
Glass of all kinds.	All the metals, in the following order:—
All precious stones: the most transparent the best.	Gold; silver;
Amber.	Copper; platina;
Sulphur.	Brass; iron;
All resinous substances.	Tin; quicksilver;
Wax of all kinds.	Lead.
Silk and cotton.	Solution of metallic salts.
Feathers, wool, and hair.	Metallic ores.
Paper; loaf sugar.	Charcoal.
Air, when quite dry.	Animal fluids.
Oils and metallic oxides.	Water, and other fluids, except oil.
Ashes of animal and vegetable substances.	Ice; snow.
Most hard stones: and	Most saline substances.
Earth, when quite dry.	Earthy substances.
	Smoke; steam.

QUESTIONS FOR EXAMINATION.

What is supposed to be the nature of the agent producing the phenomena of electricity?—Can substances contain more than a certain quantity of the electric fluid?—Does every substance possess a certain quantity of the electric fluid?—In what cases are sparks obtained from any bodies?—For what purpose is a glass tube used in this science?—What is meant by attraction and repulsion in this science?—In what way is the electric fluid collected?—Explain the distinction between electrics and conductors.—What other name is there for electrics?—Explain the experiment shown by fig. 1.—Examine the table.

CONVERSATION III.

OF THE ELECTRICAL MACHINE.

Father. I will now explain to you the construction of the electrical machine, and show you how to use it.

Soon after the electric fluid engaged the attention of men of science, they began to contrive the readiest methods of collecting large quantities of it. By rubbing this stick of sealing-wax, I can collect a small portion. If I excite or rub the glass tube I get still more. The object therefore was, to invent a machine, by which the largest quantities could be collected, with as little trouble and expense as possible.

Ja. You get more electricity from the tube than from the sealing-wax, because it is five or six times as large. By increasing the size of the tube, I suppose you would increase the quantity of the electric fluid.

Fa. That is a natural conclusion. But if you look to the table of non-conductors, which I made out yesterday, you will see that, had the wax been as large as the glass tube, it would not have collected so much of the electric fluid; because, in its own nature, it is not so good an electric.

Ch. By the table, glass stands as the most perfect electric: but there are several substances between it and wax; all of which are, I believe, more perfect electrics than wax.

Fa. Certainly: electricians, therefore, had no doubt as to the nature of the substance: they fixed on glass; which, being easily melted and blown into all sorts of forms, is, on that account, very valuable.

The most common form now used is that of a glass cylinder, from five or six inches in diameter, to ten or twelve in length. Here is one completely fitted up. The cylinder, A B, is about eight inches in diameter, and twelve in length. This I turn round in the frame-work with the handle D C.

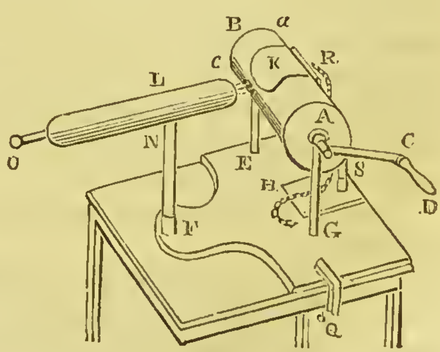


Fig. 2.

Ja. What is the piece of black silk, K, for?

Fa. The cylinder would be of no use without a rubber: on which account you see the glass pillar, R S, which, being cemented into a piece of hard wood, is made to screw into the bottom of the machine. On the pillar is a cushion, to which is attached the piece of black silk. The cushion is generally made of soft leather, and stuffed with horse hair or wool, just as the cushions of chairs are made.

Ch. And I perceive the cushion is made to press hard against the glass.

Fa. This pressure, when the cylinder is turned round quickly, acts precisely like the rubbing of the tube on the woollen cloth, though in a still more perfect manner. I will turn it round.

Ja. I do not see much sign of electricity yet.

Fa. No: the machine is complete; but it has no means of collecting the fluid from the surrounding bodies: for, you see, the cushion or rubber is fixed on a glass pillar; and glass will not conduct the electric fluid.

Ch. Nevertheless, by turning round, it shows some signs of attraction.

Fa. Every substance in nature, with which we are acquainted, possesses a portion of this fluid; and therefore the signs which are now evident arise from the small quantity existing in the rubber itself, and the atmosphere that immediately surrounds the machine.

Ch. Would the case be different, if the rubber were fixed on a conducting substance, instead of glass?

Fa. It would. But there is a much easier method: I will hang this brass chain on the cushion at R, which, being several feet long, lies on the table, or on the floor; and this, you perceive, is connected, by means of other objects, with the earth, which is the grand reservoir of the electric fluid. Now see the effect of turning round the cylinder. But I must make every part of it dry and rather warm, by rubbing it with a dry warm cloth.

Ja. It is indeed very powerful. What a crackling noise it makes!

Fa. Yes; now shut the window-shutters.

Ch. The appearance is very beautiful: the flashes from the silk dart all round the cylinder.

Fa. I will now bring to the cylinder the tin conductor, L, which is also placed on a glass pillar, F N, fixed in the stand at F.

Ja. What is the use of the points in the tin conductor?

Fa. They are intended to collect the fluid from the cylinder. I will turn the cylinder; and now hold your knuckle within four or five inches of the conductor.

Ch. The painful sensations which these sparks occasion prove that the electric fluid is a very powerful agent, when collected in large quantities.

Fa. To show you the nature of conducting bodies, I will now throw another brass chain over the conductor; so that one end of it may lie on the floor. See, now, if you can get any sparks while I turn the machine.

Ja. No, none, however near I put my knuckle. Does it all run away by the chain?

Fa. It does: a piece of brass or iron wire would do as well; and so would any conducting substance which touched the conductor with one end, and the floor with the other. Your body would do as well as the chain. Place your hand on the conductor while I turn round the cylinder: and let your brother bring his knuckle near the conductor.

Ch. I can get no spark.

Fa. It runs through your brother to the earth; and you see that his body is a conductor, as well as the chain. With a very little contrivance, I can take sparks from you or James, as well as you did from the conductor.

Ja. I should like to see how that is done

Fa. Here is a small stool, having a mahogany top and glass legs. If you stand on it, and put your hand on the conductor, the electricity will pass from the conductor to your body.

Ch. Will the glass legs prevent it from running from him to the earth?

Fa. They will: and therefore what he receives from the conductor, he will give off to any of the surrounding bodies, or to you, if you bring your hand near enough to any part of him.

Ja. The sparks are more painful when coming through my clothes, than when I received them on my bare hand.

Fa. You understand, I hope, this process.

Ch. By means of the chain trailing on the ground, the electric fluid is collected from the earth on the glass cylinder, which gives it, through the points, to the conductor. From this it may be conveyed away again by means of other conductors.

Fa. Whenever a body is supported or prevented from

touching the earth, or communicating with it, by means of glass or other non-conducting substances, it is said to be *insulated.* Thus, a body suspended on a silk thread is insulated; and so is any substance that stands on glass, or resin, or wax, provided that these be in a dry state; for moisture will conduct away the electric fluid from any charged body.

QUESTIONS FOR EXAMINATION.

For what is the electrical machine used?—Explain the parts as represented in fig. 2. — How does the cushion act? — What connects the machine with the surrounding bodies? — What is the grand reservoir of the electric fluid? — How is the electric fluid collected from the cylinder?—What proof is there that the electric fluid is a very powerful agent? — How are electrical sparks taken from the human body? — What prevents it from running to the earth? — What is meant by insulating a body?

CONVERSATION IV

OF THE ELECTRICAL MACHINE — *continued.*

Charles. What is that shining stuff which I saw you put on the rubber yesterday?

Fa. It is called *amalgam:* the rubber, by itself, would produce a very slight excitation; but its power is greatly increased by laying upon it a little of this amalgam, which is made of quicksilver, zinc, and tinfoil, with a little tallow or mutton suet: the best amalgam is that recommended by Mr. Singer, which is composed of one ounce of tin melted with two ounces of zinc, and this in a state of fluidity is to be mixed with six ounces of mercury, and the whole well triturated in a wooden mortar till cold. It is now to be made into a fine powder, and mixed with enough hog's lard to form it into a paste.

Ja. Is there any art required in using this amalgam?

Fa. When the rubber and silk flap are very clean and dry, and in their place, then spread a little of the amalgam upon a piece of leather, and apply it to the under part of the glass cylinder, while it is revolving from you. By this application particles of the amalgam will be carried by the glass itself to the lower part of the rubber, and will increase the excitation.

Ch. I think I once saw a globe, instead of a cylinder, for an electrical machine.

Fa. You might: globes were used before cylinders; but the latter are the most convenient of the two. The most pow-

erful electrical machines are fitted with flat plates of glass. In our experiments, we shall be content with the cylinder, which will answer every purpose of explaining the principles of the science.

Ja. As I was able to conduct the electricity from the tin conductor to the ground, could I likewise act the part of the chain by conducting the fluid from the earth to the cushion?

Fa. Undoubtedly: I will take off the chain, and now, you keep your hand on the cushion, while I turn the handle.

Ja. I see the machine works as well as when the chain was on the ground.

Fa. Keep your present position; but stand on the stool with glass legs; by which means all communication is now cut off between the cushion and the earth: in other words, the cushion is completely insulated, and can only take from you what electricity it can get from your body. Go, Charles, and shake hands with your brother.

Ch. It does not appear that the machine had taken all the electricity from him; for he gave me a smart spark.

Fa. You are mistaken: he gave you nothing; but he took a spark from you.

Ch. I stood on the ground. I was not electrified. How, then, could I give him a spark?

Fa. The machine had taken from your brother the electricity that was in his body, and by standing on the stool, (that is, by being insulated,) he had no means of receiving any more from the earth, or any surrounding objects: the moment, therefore, you brought your hand near him, the electricity passed from you to him.

Ch. I certainly felt the spark; but whether it went out of, or entered into my hand, I cannot tell. Have I, then, less than my share now?

Fa. No: what you gave to your brother, was supplied immediately from the earth. Here is another glass-legged stool. Stand on this at the distance of a foot or two from your brother, who still keeps his place. I will take the electricity from him by turning the machine; and, as he stands on the stool, he has now less than his share. But you have your natural share, because, though you also are insulated, yet you are out of the influence of the machine. Extend, therefore, your hand, and give him a part of the electric fluid that is in you.

Ch. I have given him a spark.

Fa. And being yourself insulated, you have now less than your natural quantity; to supply which, you shall have some from me. Give me your hand. Why, you draw it back without my touching it.

Ch. I did; but it was near enough to get a strong spark from you.

Fa. When a person has *less* electricity than his natural share, he is said to be electrified *minus*, (—) or negatively: but if he has *more* than his natural share, he is said to be electrified *plus*, (+) or positively.

Ja. Then, before Charles gave me the spark, I was electrified minus, and when he had given it me, he was minus till he received it from you.

Fa. Certainly. Suppose you stand on a stool, and hold the rubber, and Charles stand on another stool, and touch the prime conductor L, while I turn the machine; which of you will be plus, and which minus electrified?

Ja. I shall be minus, because I give to the rubber: and Charles will be plus, because he receives from the conductor what I gave to the rubber, and which is carried by the cylinder to the conductor.

Fa. You then have less than your share, and your brother has more than he ought to have. Now, if I get another glass-legged stool, I can take from Charles what he has too much, and give it to you who have too little.

Ch. Is it necessary that you should be insulated for this purpose?

Fa. By being insulated, I may perhaps carry back to James the very electricity which passed from him to you. But if I stand on the ground, the quantity which I take from you will pass into the earth, because I cannot, unless I am insulated, retain more than my natural share.

Ja. And is the quantity I have received from you likewise instantaneously supplied by the earth?

Fa. It is. Let us make another experiment, to show that the electric fluid is taken from the earth. Here are some little balls made of the pith of elder: they are put on thread, and being very light, are well adapted to our purpose.

While the chain is on the cushion, and I

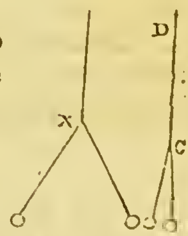


Fig. 3. a b

work the machine, you must bring the balls near the conductor, by holding the thread at D.

Ja. They are attracted by it; and now the two balls repel each other, as in the figure X.

Fa. I ought to have told you, that the upper part, D, of the thread is silk, by which you are aware that the balls are insulated; as silk is a non-conductor. I will take the chain from the cushion, and put it on the conductor, so as to allow it to hang on the ground, while I turn the machine. Will the balls be affected now, if you hold them to the conductor?

Ja. No.

Fa. Take them to the cushion.

Ch. They are attracted and repelled now, by being brought near the cushion, as they were before, by being carried to the conductor.

Fa. Yes; and you may now take sparks from the cushion as you did from the conductor: in both cases it must be evident that the electric fluid is brought from the earth.

Some machines are furnished with two *conductors;* one of which is connected with the cushion; the other such as we have described. Turn the cylinder, and both conductors will be electrified; but any substance brought within the influence of these will be attracted by one of the conductors, and repelled by the other: and if a chain or wire be made to connect the two together, neither will exhibit any electric appearances: they seem, therefore, to be in opposite states. Accordingly, electricians say that the conductor connected with the cushion is *negatively* electrified, and the other *positively* electrified, and substances are accordingly called either electro-positive or electro-negative bodies.

QUESTIONS FOR EXAMINATION.

What is the composition of amalgam, and for what is it used? — Explain the mode in which sparks are conveyed from one to another. — How is a person said to be electrified who has less of the fluid than his natural share? —How, when he has more? — Explain the experiment of the pith balls, fig. 3. — For what are two conductors used in some machines?

CONVERSATION V

OF ELECTRICAL ATTRACTION AND REPULSION.

James. What is this large roll of sealing-wax for?

Fa. As I mean to explain, this morning, the principles of eleetrical attraction and repulsion, I have brought out, in addition to the electrical maehine, the long glass tube, and a roll of sealing-wax, about fifteen inches long, and an inch and a quarter in diameter.

Ch. Are they not both eleetries, and eapable of being exeited?

Fa. Yes: but the electricity produced by exciting them has eontrary properties.

Ja. There are then two kinds of electricities, I suppose?

Fa. I will show you an experiment before I attempt to give any theoretical exposition. I will excite the glass tube and Charles shall excite the wax. Now, you bring the pith-balls, which are suspended on silk, to the tube: they are suddenly drawn to it; and now they are repelled from one another, and likewise from the tube; for you cannot easily make them touch it again: — but take them to the excited wax.

Ja. The wax attracts them very powerfully: now they fall together again; and appear in the same state as when they were brought to the excited tube.

Fa. Repeat the experiment again and again; because from this, two different theories have been formed. One of which is, that there are two electricities, ealled by some philosophers the *vitreous* or positive electricity, and the *resinous* or negative electricity.

Ch. Why are they ealled *vitreous* and *resinous?*

Fa. The word vitreous is from the Latin, and signifies any *glassy* substance; and the word resinous is used to denote that the electricity produced by resins, wax, &e., possesses different qualities from that produeed by glass.

Ja. Is it not natural to suppose that there are two electricities, since the excited wax attracts the very same bodies that the excited glass repels?

Fa. It may be as easily explained, by supposing that every body, in its natural state, possesses a certain quantity of the

electric fluid; and if a part of it be taken away, it endeavours to get it from other bodies; or if more be thrown upon it than its natural quantity, it yields it readily to other bodies that come within its influence.

Ch. I do not understand this.

Fa. If I excite this glass tube, the electricity which it exhibits is supposed to come from my hand; but if I excite the roll of wax in the same way, the effect is, according to this theory, that a part of the electric fluid, naturally belonging to the wax, passes from it through my hand to the earth: and the wax being surrounded by the air, which, in its dry state, is a non-conductor, remains exhausted, and is ready to take sparks from any body that may be presented to it.

Ja. Can you distinguish that the sparks come from the glass to the hand: and, on the contrary, from the hand to the wax?

Fa. No: the velocity with which light, and, of course, the electric spark, moves, renders it impossible to say what course it takes; but I shall show you other experiments which seem to justify this theory: and as nature always works by the simplest means, it seems more consistent with her usual operations that there should be one fluid rather than two, provided that known facts can be equally well accounted for by one as by two.

Ch. Can you account for all the leading facts by either theory?

Fa. Yes, I think so.

You saw when the pith balls were electrified, they repelled one another. It is a general principle in electricity, that two bodies, having more than their natural share of the electric fluid, will repel one another. But if one have more, and the other less than its share, they will attract one another.

Ja. How is this shown?

Fa. I will hold this ball, which is insulated by a silk thread, to the conductor, and you, Charles, do the same with the other. Let us now bring them together.

Ch. I perceive we cannot: they fly from one another.

Fa. I will hold mine to the insulated cushion, and you shall hold yours to the conductor, while the machine is turned: now I suspect they will attract one another.

Ja. They do, indeed.

Ch. The reason is this, I suppose: the cushion. and whatever is in contact with it, parts with a portion of its electricity; but the conductor and the adjoining bodies have more than their share; therefore, the ball applied to the cushion, being negatively electrified, will attract the one connected with the conductor, which is positively electrified.

Fa. Here is a tuft of feathers, which I will stick in a small hole in the conductor: now see what happens to them when I turn the cylinder.

Ja. They all endeavour to avoid each other, and stand erect, in a very beautiful manner. Let me take a spark from the conductor. Now they fall down in a moment.

Fa. When I turned the wheel, they all had more than their share of the electric fluid, and therefore they repelled one another; but the moment the electricity was taken away, they fell into their natural position. A large plume of feathers, when electrified, grows beautifully turgid, expanding its fibres in all directions; and they collapse when the electricity is taken off.

Ja. Could you make the hairs on my head repel one another?

Fa. Yes, I could, indeed. Stand on the glass-legged stool, and hold the chain that hangs on the conductor in your hand, while I turn the machine.

Ch. Now your hairs stand all on end.

Ja. And I feel something like cobwebs over my face.

Fa. There are, however, no cobwebs: but that is a sensation which a person always experiences if he is highly electrified. Hold the pith ball, Charles, near your brother's face.

Ja. It is attracted in the same manner as it was before with the conductor.

Fa. Hence you may lay it down as a general rule, that all light substances coming within the influence of an electrified body are attracted by it, whether electrified positively or negatively.

Ch. Because they are attracted by the positive electricity to receive some of the superabundant quantity; and by the negative, to give away some that they possess.

Fa. Just so: and when they have received as much as

they can contain, they are repelled by the electrified body The same thing may be shown in various ways. Having excited this glass tube, either by rubbing it several times on the cloth of my coat sleeve, or by means of a piece of flannel, I will bring it near this small feather. See how quickly it springs to the glass.

Ja. It does, and sticks to it too.

Fa. You will observe that, after a minute or two, it will have taken as much electricity from the tube as it can hold; when it will suddenly be repelled, and spring to the nearest conductor; upon which it will discharge the superabundant electricity that it has acquired.

Ja. I see it is now going to the ground—that being the nearest conductor.

Fa. I will prevent it, by holding the electrified tube between it and the floor. You see how unwilling it is to come again in contact with the tube: by pursuing it, I can drive it where I please without touching it.

Ch. That is, because the glass and the feather are both loaded with the same electricity.

Fa. Let the feather touch the ground, or any other conductor, and you will see that it will spring to the tube as nimbly as it did before.

I will suspend this brass plate, which is about five inches in diameter, to the conductor; and at the distance of three or four inches below I will place some small feathers, or bits of paper cut into the figures of men and women. They lie very quiet at present: but observe their motions as soon as I turn the wheel.

Ja. They appear to represent dancing figures; they jump up to the plate and down again.

Fa. The same principle is evident in all these experiments. The upper plate has more than its own share of the electric fluid, which attracts the little figures. As soon as they have received a portion of it, they go down to give it to the lower plate; and so it will continue till the upper plate is divested of its superabundant quantity.

I will take away the plates, and hang a chain on the conductor, the end of which shall lie in several folds in a glass tumbler: if I turn the machine, the electric fluid will run

through the chain, and will electrify the inside of the glass. This being done, I will then turn it quickly over eight or ten small pith balls, which lie on the table.

Ch. That is a very amusing sight. How they jump about! They serve to carry the electricity from the glass to the table.

Fa. If, instead of the lower metal plate, I hold in my hand a pane of dry and clean glass, by the corner, the paper figures, or pith balls, will not move, because, glass being a non-conducting substance, it has no power of carrying away the superabundant electricity from the plate suspended from the conductor. But, if I hold the glass flat in my hand, the figures will be attracted and repelled: which shows that the electric fluid will pass through thin glass. I will here give you a list of a few substances which take vitreous electricity if rubbed with the body immediately following it, but resinous electricity if rubbed with the one immediately preceding.

The back of a cat.	Wood
Smooth glass.	Paper.
Woollen cloth.	Silk.
Feathers.	

Now take down on paper the following results, and commit them to memory.

1. If two insulated pith balls be brought near the conductor, they will repel each other.

2. If an insulated conductor be connected with the cushion, and two insulated pith balls be electrified by it, they will repel each other.

3. If one insulated ball be electrified by the prime conductor, and another by the conductor connected with the cushion, they will attract each other.

4. If one ball be electrified by glass, and another by wax, they will attract each other.

5. If one ball be electrified by a smooth, and another by a rough excited glass tube, they will attract one another.

QUESTIONS FOR EXAMINATION.

Explain the nature of vitreous and desinous electricity, and why they are so called.—How are the two kinds of electricity explained?—Can the course of the electric spark be traced?—Is it the more natural theory that there should be one or two electric fluids?—On the supposition of one fluid only,

can the facts be accounted for? — Illustrate this with the pith balls. — How is the experiment of the tuft of feathers explained? — How is the hair on the head affected by electricity? — What particular sensation does an electrified person usually feel? — What is the general rule on this subject? — How do you show that, when a body has received as much electricity as it can contain, it will be repelled by another electrified body? — How is the experiment of the dancing figures explained? — What will happen if two insulated pith balls be brought near the electrified conductor of a machine? — In what case will pith balls repel each other? — In what cases will there be an attraction between them? — What will be the result if one pith ball be electrified with wax and another with glass? — Will the result be the same if the balls be electrified, one with smooth and another with rough glass?

CONVERSATION VI.

OF ELECTRICAL ATTRACTION AND REPULSION.

Father. I will show you another instance or two of the effects of electrical attraction and repulsion.

This apparatus consists of three bells suspended from a brass wire; the two outer ones by small brass chains; the middle bell, and the two clappers, *x x*, are suspended on silk. From the middle bell there is a chain, N, which goes to the table, or any other conducting substance. The bells are now to be hung by C on the conductor, and the electrical machine to be put in motion.

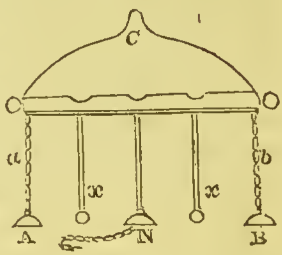


Fig. 4.

Ja. The clappers go from bell to bell, and make very pretty music: how do you explain that?

Fa. The electric fluid runs down the chains *a* and *b* to the bells, A B: these, having more than their natural quantity, attract the clappers, *x x*, which take a portion from A and B, and carry it to the centre bell, N; and this, by means of the chain, conveys it to the earth.

Ch. Would not the same effect be produced if the clappers were not suspended by silk?

Fa. Certainly not: nor will it be produced if the chain be taken away from the bell N, because then there is no way left to carry off the electric fluid to the earth.

Another amusing experiment is thus shown:—Let there be two wires placed exactly one above another, and parallel: the

upper one must be suspended from the conductor; the other is to communicate with the table: a light image, placed between these, will, when the conductor is electrified, appear like a rope-dancer.

This piece of leaf brass is called the *electric fish:* one end is a sort of obtuse angle; the other is acute. If the large end be presented towards an electrified conductor, it will adhere to it, and, from its wavering motion, appear to be animated.

This property of attraction and repulsion has led to the inventions of many instruments called electrometers.

Ja. Is not an electrometer a machine to measure the strength of the electricity?

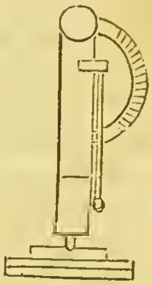


Fig. 5.

Fa. Yes; and this is one of the most simple; and it depends entirely upon the repulsion which takes place between two bodies in a state of electrification. It consists of a slender rod, terminated by a pith ball hanging parallel to the stem, but turning on the centre of a wooden or iron semicircle, so as to keep close to its graduated limb. This is fitted to a hole in the conductor, and the more the conductor is electrified, the farther will the ball fly from the stem; and the number of degrees described by the index conveys some idea of the quantity of electricity.

Ch. If the circular part be marked with degrees, you may ascertain, I suppose, pretty accurately, the strength of any given charge?

Fa. Yes, you may; but you see how fast the air carries away the electricity: it scarcely remains a single moment in the place to which it was repelled. Two pith balls may be suspended parallel to one another, on silken threads, and applied to any part of an electrical machine; and they will, by their repulsion, serve for an electrometer; for they will repel each other in proportion to the power given to the machine.

Ja. Has this any advantage over the other?

Fa. It serves to show whether the electricity be negative or positive: for if it be positive, the threads will fall together again, if you apply an excited stick of sealing-wax; but if it be negative, excited sealing-wax, or resin, or sulphur, or even a rod of glass, the polish of which is taken off, will make them recede farther.

There is another kind of electrical machine, called the Plate Machine, invented by Dr. Fryenbourg, and which has subsequently been much improved, especially by Cuthbertson. It consists of a circular plate of glass, revolving in a vertical position, on an axis passing horizontally and at right angles through its centre: it is rubbed by two pairs of cushions, one above and one below, attached to the frame, and so regulated as to employ an elastic pressure on the circumference of the plate, which each pair embraces with the necessary force; a brass conductor, with branching extremities, is attached at right angles to the pairs of cushions, and is supported by a glass stem; while pointed wires are affixed to the extremities of the branches, to collect the electricity from the plate. This machine, however, is more expensive than the other, and more liable to accidents.

We have now, perhaps, said enough respecting electrical attraction and repulsion, at least for the present: I wish you, however, to commit the following results to your memory:—

I. Bodies electrified positively repel each other.

II. Bodies electrified negatively repel each other.

Ch. Do you mean, that if two bodies have either more or less of the electric fluid than their natural share, they will repel each other if brought sufficiently near?

Fa. Exactly so.

III. Bodies electrified by contrary powers—that is, two bodies, one having more, and the other less than its natural share—attract each other very strongly.

IV. Bodies that are electrified attract light substances which are not electrified.

These are facts which, I hope, I have made sufficiently evident to you. To-morrow we will describe what is usually called the "Leyden Phial."

QUESTIONS FOR EXAMINATION.

Explain the experiment of the bells. —What do you mean by the electric fish? — For what is an electrometer used? — Look to fig. 5, and explain the nature of the instrument. — How is it discovered whether electricity is negative or positive? — When do electrified bodies repel each other? — Under what circumstances do they attract each other?

CONVERSATION VII.

OF THE LEYDEN PHIAL, OR JAR.

Father. I will take away the wires and the ball from the conductor, and then remove the latter an inch or two farther from the cylinder. If the machine acts strongly, bring an insulated pith ball (that is, one hanging on silk) to the end of the conductor nearest to the glass cylinder.

Ch. It is, I perceive, immediately attracted.

Fa. Carry it to the other end of the conductor, and see what happens.

Ch. It is attracted again, but I thought it would have been repelled.

Fa. Then, as the ball was electrified before, and is still *attracted*, you are sure that the electricity of the two ends of the conductor is differently named; that is, one is *plus*, and the other *minus*.

Ja. Which is the positive, and which the negative end?

Fa. That end of the conductor which is nearest to the cylinder becomes possessed of an electricity different from that of the cylinder itself.

Ja. Do you mean, that if the cylinder is positively electrified, the end of the conductor next to it is negatively electrified?

Fa. I do: and this you may see by holding an insulated pith ball between them.

Ch. Yes: it is now very evident; for the ball fetches and carries, as we have seen it before.

Fa. What you have seen with regard to the conductor is equally true with respect to non-conducting bodies. Here is a common glass tumbler, if I throw into it a greater portion of electricity than it naturally possesses, and hold it in my hand, or place it on any conducting substance, as the table, a part of the electric fluid, that naturally belongs to the outside, will make its escape through my body.

Ch. Let me try it.

Fa. But you must be careful not to break the glass.

Ch. I will hang the chain on the conductor, and let the other end lie on the bottom of the glass; and James will turn the machine.

Fa. You must also take care that the chain does not touch the edge of the glass; because thereby the electric fluid would run from one side of it to the other, and spoil the experiment.

Ja. If I have turned the machine enough, take the chain out, and try the two sides with the insulated pith ball.

Ch. What is this? Something has pierced through my arms and shoulders.

Fa. That is a trifling electrical shock, which you might have avoided, if you had waited for my directions.

Ch. Indeed it was not trifling: I feel it now.

Fa. This leads us to the Leyden Phial, or Jar, so called, because the discovery was first made at Leyden, in Holland, and by means of a phial or small bottle.

Ja. Was it found out in the same manner as Charles has just discovered it?

Fa. Nearly so: Cuneus, a Dutch philosopher, was holding a glass phial in his hand, about half filled with water; but the sides above the water, and the outside was quite dry; a wire also hung from the conductor of an electrical machine into the water.

Ja. Did that answer to the chain?

Fa. Yes; and, like Charles, he was going to disengage the wire with one hand, as he held the bottle in the other, and was surprised and alarmed by a sudden shock in his arms, and through his breast, which he had not the least expected.

Ch. I do not think there was anything to be alarmed at.

Fa. The shock which he felt was probably something severer than that which you have just experienced: but the terror was evidently increased by coming so completely unexpected.

When Muschenbroeck first felt the shock, which resulted from a thin glass bowl, and very slight, he wrote to Reaumur, that he felt himself struck in his arms, shoulders, and breast, so violently, that he lost his breath, and was two whole days before he recovered from the effects of the blow.

Ch. Perhaps he meant the fright?

Fa. Terror seems to have been the effect of the shock: for he adds, "I would not take a second shock for the whole kingdom of France."

Winkler, an experimental philosopher at Leipsic, describes the shock as having given him convulsions, and a heaviness

in his head, such as he should feel if a large stone were on it; and he had reason to dread a fever, to prevent which he put himself on a course of cooling medicines. "Twice," says he, "it gave me a bleeding at the nose, to which I am not subject, and my wife, whose curiosity surpassed her fears, received the shock twice, and found herself so weak, that she could scarcely walk: nevertheless, in the course of a few days she received another shock, which caused a bleeding at the nose."

Ja. Is this called the Leyden Phial?

Fa. It is. They are now made in this manner. B A is a thin glass jar, covered both inside and out with tin-foil about three parts of the way up, as far as *x*.

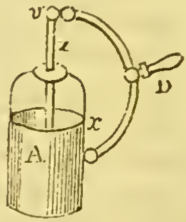


Fig. 6.

Ch. Does the outside covering answer to the hand, and the inside covering to the water?

Fa. Yes: the piece of wood *z* is placed on the top, merely to support the brass wire and knob *v*, to the bottom of which hangs a chain that rests on the bottom of the jar. I will now set the jar in such a situation that it shall be within two or three inches of the prime conductor while I work the machine.

Ja. The sparks fly rapidly from the conductor to the knob.

Fa. By that means the inside of the jar becomes charged with a superabundant quantity of electricity: and, as it cannot contain this without, at the same time, driving away an equal quantity from the outside, the inside is positively electrified, and the outside negatively electrified. To restore the equilibrium, I must make a communication between the outside and inside with some conducting substance; that is, I must make the same substance touch, at the same time, the outside tin-foil, and that which is within, or, which is the same thing, another substance that does touch it.

Ch. The brass wire touches the inside: if I, therefore, with one hand touch the knob, and with the other the outside covering, will it be sufficient?

Fa. It will: but I had rather you would not, because the shock will be more powerful than I should wish either myself or you to experience. Here is a brass wire with two little balls or knobs, *b s*, to it. I will

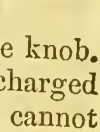


Fig. 7.

now bring one of them, *s*, to the outside, and the other, *b*, to the ball, *v*, on the wire.

Ja. What a brilliant spark, and what a loud noise!

Fa. The electric fluid that occasions the light and the noise ran from the inside of the jar along the wire to *s*, and spread itself over the outside.

Ch. Would it have gone through my arms if I had put one hand to the outside, and touched the wire communicating with the inside with the other?

Fa. It would; and you may believe that the shock would have been in proportion to the quantity of the fluid collected. The instrument I used may be called a discharging rod: but here is a more convenient one: the handle, D, is solid glass, fastened into a brass socket, and the brass work is the same as fig. 7, except that, by turning on a joint, the arms may be opened to any extent.

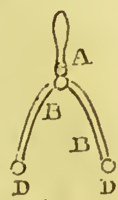


Fig. 8.

Ja. Why is the handle made of glass?

Fa. Because glass being a non-conductor, the electric fluid passes through the brass work, without affecting the hand; whereas, with the other, a small sensation was perceived while I discharged the jar.

Ch. Would the jar never discharge itself?

Fa. Yes: by exposure to the air for some time, the charge of the jar will be silently and gradually dissipated; for the superabundant electric fluid of the inside will escape, by means of the air, to the outside of the jar. Electricians, however, make it a rule never to leave a jar in its charged state.

QUESTIONS FOR EXAMINATION.

How is it known that the ends of an electrified conductor possess the plus and minus electricity? — Is it known which is positive and which negative? — Suppose more electricity than its natural share is thrown into the inside of a glass tumbler, in what state will the outside be? — Where and how was the Leyden phial discovered? — How does Muschenbroeck describe the electrical shock? — How is it described by Winkler? — How is the Leyden phial constructed, and how are its effects explained? — How is the equilibrium restored? — For what is the machine, represented by fig. 7, used? — How would the shock be conveyed through the body? — What do you mean by a discharging rod? — Why have discharging rods glass handles? — Would an electrified body ever discharge itself?

CONVERSATION VIII.

OF THE LEYDEN JAR: LANE'S DISCHARGING ELECTROMETER, AND THE ELECTRICAL BATTERY

Charles. In discharging the jar yesterday, I observed, that when one of the discharging rods touched the outside of the jar, the flash and report took place before the other end came in contact with the brass wire that communicates with the inside coating.

Fa. Yes; it acts in the same manner as when you take a spark from the conductor. You do not, for that purpose, bring your knuckle close to the tin.

Ja. Sometimes, when the machine acts very powerfully, you may get the spark at the distance of several inches.

Fa. By the same principle, the higher an electrical or Leyden jar is charged, the more easily, or at a greater distance, it is discharged.

Ch. From your experiments it does not seem that it will discharge at so great a distance as that in which a spark may be taken from the conductor.

Fa. Very frequently a jar will discharge itself, after it has accumulated as much of the electrical fluid as it can contain; that is, the fluid which is thrown on the inside coating will make its way over the glass, though a non-conductor, to the outside coating.

Ja. In a Leyden jar, after the first discharge, you always, I perceive, take another and smaller one.

Fa. The tin-foil on the jar not being a perfect conductor, the whole quantity of fluid will not pass at first from the inside to the out: what remains is called the *residuary charge*, and this, in a large jar, would still give a considerable shock: therefore, in discharging an electrical jar, it is always advisable to take away the residuum before you venture to remove the apparatus. I will now describe an Electrometer, which depends, for its action, on the principles we have been describing.

Ch. Do you mean that it depends upon the discharging of the jar before the outside and inside coating are actually brought into contact?

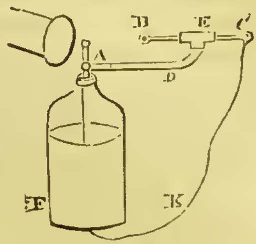


Fig. 9.

Fa. I do. The arm D is made of glass, and proceeds from a socket on the wire of the electrical jar F. To the top of the glass arm is cemented another brass socket E, through which a wire, with balls, B and C, at each end, will slide backwards and forwards.

Ja. So that it may be brought to any distance from the ball A, which is on the wire connected with the inside of the jar?

Fa. Yes. When the jar F is set in contact, or very near the conductor, as represented in the figure, and the ball B is set at the distance of the eighth of an inch from the ball A, let a wire, C K, be fixed between the ball C and the outside coating of the jar. Then, as soon as the machine is worked, the jar cannot be charged beyond a certain point: for when the charge is strong enough to pass from A to the ball B, the discharge will take place, and the electric fluid collected in the inside will pass through the wire C K to the outside coating.

Ch. If you remove the balls to a greater distance from one another, will a stronger charge be required before the fluid can pass from the inside of the jar to the ball B of the electrometer?

Fa. Certainly: and therefore the discharge will be much stronger. This machine is called Lane's Discharging Electrometer, from the name of the person who invented it, and the power of the machine may be ascertained from the number of explosions which at any given distance take place in equal times. It is very useful in applying the electric shock to medical purposes, as we shall see hereafter.

If we were to combine together several jars, we could obtain a very great quantity of electricity, but in this case the interior coatings of the jars must communicate by means of metallic rods, and so likewise the exterior coatings. This combined set of jars may be charged as if but one jar, and they would have extraordinary power; and this is what is called an *Electrical Battery.*

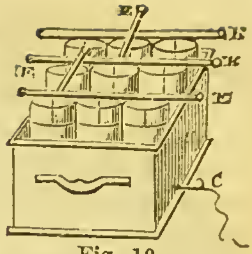


Fig. 10.

This box contains nine jars, or Leyden phials: the wires which proceed from the inside of each three of these jars are screwed or fastened to a common horizontal wire E, which has a knob at each extremity, and by means of the wires F F, the inside coatings of 3 or 6, or the whole 9 may be connected.

Ja. Is it a common box in which the jars are placed?

Fa. The inside of the box is lined with tin-foil: sometimes very thin tin plates are used, for the purpose of connecting more effectually the outside coatings of all the jars.

Ch. For what purpose is the hook on one side of the box?

Fa. To this hook is fastened a strong wire, which communicates with the inside lining of the box, and, of course, with the outside coating of the jars. You see also that a wire is fastened to the hook, which connects it with one branch of the discharging rod.

Ja. Is there any particular art to be used in charging a battery.

Fa. No: the best way is, to bring a chain, or piece of wire, from the conductor to one of the balls on the rods that rest upon the jars: and then set the machine to work. The electric fluid passes from the conductor to the inside of all the jars, till it is charged sufficiently high for the purpose. Great caution, however, must be used when you come to make experiments with a battery, to prevent accident either to yourself or to the spectators.

Ch. Would a shock from this be attended with any bad consequences?

Fa. Yes: very serious accidents may happen from the electricity accumulated in a large battery, and even with a battery such as is represented in the plate, which is one of the smallest in use. A shock may be given, which, if passed through the head, or any other vital part of the body, may be attended with very mischievous effects.

Ja. How do you know when the battery is properly charged?

Fa. The quadrant electrometer (fig. 5.) is the best guide: and this may be fixed either on the conductor or upon one of the rods of the battery. But if it be fixed on the battery, the

stem of it should be of a good length; not less than 12 or 15 inches.

Ch. How high will the index stand when the battery is charged?

Fa. It will seldom rise so high as 90°, because a machine, under the most favourable circumstances, cannot charge a battery so high, in proportion, as a single jar. You may reckon that a battery is well charged when the index rises as high as 60°, or between that and 70°.

Ja. Is there no danger of breaking the jars when the battery is very highly charged?

Fa. Yes, there is: and if one jar be cracked, it is impossible to charge the others till the broken one be removed. To prevent accidents, it is recommended not to discharge a battery through a good conductor, unless the circuit be at least five feet long.

Ch. Do you mean that the wire should be of that length?

Fa. Yes, if you pass the charge through that: but you may carry it through any conductor.

Before a battery is used, the uncoated part of the jars must be made perfectly clean and dry, as the smallest particles of dust will carry off the electric fluid. After a discharge, never fail to connect the wire from the hook with the ball, to prevent any residuum.

QUESTIONS FOR EXAMINATION.

What is meant in electricity by the word residuum? — Explain the nature and uses of the electrometer, fig. 10.— Who invented it, and for what purposes is it usually applied? — Explain the construction of an electrical battery. — How is it charged? — May not the charge of a battery be attended with dangerous effects? — For what is the quadrant electrometer used? — When do you know that the battery is properly charged? — In what case will not a battery act, and how are accidents prevented? — What precautions are necessary in using the battery?

CONVERSATION IX.

EXPERIMENTS MADE WITH THE ELECTRICAL BATTERY.

Father. I will now show you some experiments with this large battery. To perform these with perfect safety, you must stand some distance from it, which will preserve you from accidents.

Experiment I.—I will take this quire of writing paper, and place it against the hook or wire proceeding from the box; and when the battery is charged, I will put one ball of the discharging rod to a knob of one of the wires, F, and bring the other knob to that part of the paper which stands against the wire connected with the box. You see what a hole it has made through every sheet of the paper. Smell the paper where the perforation is.

Ch. It smells like sulphur.

Fa. Or more like phosphorus. Did you observe, in this experiment, that the electric fluid passed from the inside of the jars, through the conducting rod and paper, to the outside?

Ja. Yes; why did it not pass through the paper, as it passed the brass discharging rod, without making a hole?

Fa. Paper is a non-conductor, but brass is a conductor. Through the latter it passes without any resistance; but in its endeavour to get to the inside of the box, it burst the paper, as you see. The same thing would have happened if there had been twice or thrice as much paper. The electric fluid of a single jar will pierce through very many sheets of paper.

Ch. Would it affect any other non-conducting substance in the same manner?

Fa. Yes; it will even break a thin piece of glass, or resin, or sealing-wax, if it be interposed between the discharging rod and the outside of the coating of the battery.

Ex. II.—Now put a piece of loaf sugar in the place where the quire of paper was just now; the sugar will be broken, and in the dark it will appear beautifully illuminated, remaining so for many seconds.

Ex. III—Let the small piece of wire proceeding from the hole in the box be laid on one side of a plate containing some spirits of wine, and, on the opposite side of the plate, place one of the knobs of the discharging rod, while the other is carried to the wires connected with the inside of the jars.

Ch. Will the electric fluid then have a passage through the spirit?

Fa. It will set it on fire instantly.

Ex. IV.—Take two slips of common window-glass, about four inches long, and one inch broad. Put a layer of gold leaf between the glasses, leaving a small part of it out at each end. Then tie the glasses together, or press them with a

heavy weight, and send the charge of the battery through it, by connecting one end of the glass with the outside of the jars, and bringing the discharging rod to the other end, and to the wires of the inside of the battery.

Ja. Will it break the glass?

Fa. It probably will; but whether it do or not, the gold leaf will be forced into the pores of the glass, so as to give the appearance of glass stained with gold, which nothing can wash away.

Ex. V.—If the gold leaf be put between two cards, and a strong charge passed through it, it will be completely fused or melted; and the marks of it will appear on the card.

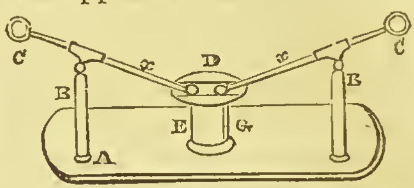


Fig. 11.

This instrument, called the Universal Discharger, is very useful for passing charges through many substances. B B are glass pillars cemented into the frame A. To each of the pillars is cemented a brass cap, and a double joint for horizontal and vertical motions. On the top of each joint is a spring tube, which holds the sliding wires C x, C x, so that they may be set at various distances from each other, and turned in any direction: the extremities of the wires are pointed, but with screws, at about half an inch from the points, to receive balls. The table, E D, inlaid with a piece of ivory, is made to move up and down in a socket, and a screw fastens it to any required height. The rings, C C, are very convenient for fixing a chain or wire to them, which proceeds from the conductor.

Ch. Do you lay anything on the ivory, between the balls, when you want to send the charge of a battery through it?

Fa. Yes: and by drawing out the wires, the balls may be separated to any distance less than the length of the ivory. The little figure, H, represents a press, which may be substituted in the place of the table, E D: it consists of two flat pieces of mahogany which may be brought together by screws.

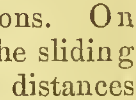


Fig. 12.

Ja. Then, instead of tying the slips of glass together in Experiment IV., you might have done it better by making use of the press?

Fa. I might; but I was willing to show you how the thing might be done if no such apparatus were at hand. The use

of the table and press, which, in fact, always go together, is for keeping steady all descriptions of bodies through which the charge of a single jar, or any number of which a battery consists, is to be conveyed. We will now proceed with the experiments.

Ex. VI.—I will take the knobs from the wires of the Universal Discharger, and having laid a piece of very dry writing-paper on the table E, I will place the points of the wires at an inch or more from one another; then, by connecting one of the rings C with the outside wire or hook of the battery, and bringing the discharging rod from the other ring C to one of the knobs of the battery, you will see that the paper will be torn to pieces.

Ex. VII.—The experiment which I am now going to make, you must never attempt by yourselves. I first put a little gunpowder in a little wooden cup, and carry the spark along a moist thread six or seven inches in length, attached to that arm of the universal discharger which is connected with the negative coat of the jar containing the charge. I now send the charge of the battery through it, and the gunpowder, you see, is instantly inflamed.

Ex. VIII.—Here is a very slender wire, not a hundredth part of an inch in diameter, which I connect with the wires of the discharger, and send the charge of a battery through it, which will completely melt it; and you now perceive the little globules of iron instead of the thin wire.

Ch. Will other wires besides iron be melted in the same manner?

Fa. Yes: if the battery be large enough, and the wires sufficiently thin, the experiment will succeed with them all; even with a single jar, if it be pretty large, very slender wire may be fused. But the charges of batteries have been used to determine the different conducting powers of the several metals.

Ja. If the charge is not strong enough to melt the wire, will it make it red-hot?

Fa. It will: and when the experiment is properly done, the course of the fluid may be discerned by its effects: for if the wire is about three inches long, it will be seen that the end of it, which is connected with the inside of the battery, is red-hot first, and the redness proceeds towards the other.

Ch. That is a clear proof that the superabundant electricity accumulated in the inside is carried to the outside of the jars.

Fa. Ex. IX.—We shall hereafter discuss the subject of Magnetism: but by discharging the battery through a small sewing needle, it will become magnetic; that is, if the needle be accurately suspended on a small piece of cork in a basin of water, one end will, of itself, point to the north, and the other to the south.

Ex. X.—I will lay this chain on a sheet of writing-paper, and send the charge of the battery through the chain; and you will see black marks will be left on the paper in those places where the rings of the chain touch each other

Ex. XI.—Place a small piece of very dry wood between the balls of the Universal Discharger, so that the fibres of the wood may be in the direction of the wires, and pass the charge of the battery through them; the wood will be torn in pieces. The points of the wires being run into the wood, and the shock passed through them, will effect the same thing.

Ex. XII.—Here is a glass tube, open at both ends, six inches long, and a quarter of an inch in diameter. These pieces of cork, with wires in them, exactly fit the ends of the tube. I will now put in one cork, and fill the tube with water, and then put in the other cork, and push the wires so that they nearly touch, and pass the charge of the battery through them. You see the tube is broken, and the water dispersed in every direction.*

Ch. If water be a good conductor, how is it that the charge did not run through it, without breaking the tube?

Fa. The electric fluid, like common fire, converts the water into a highly elastic vapour, which, occupying very suddenly a much larger space than the water, bursts the tube before it can effect its escape.

QUESTIONS FOR EXAMINATION.

Explain the experiment of piercing holes in a quire of paper.—Why is a hole made through the paper? — Will electricity tear or break other non-conducting substances? — What is the second experiment mentioned ?—How is spirit of wine inflamed ? — How can glass be stained with gold leaf ? — Can gold

* To prevent accident, a wire cage, such as is used in certain experiments on the air-pump, should be put over the tube before the discharge is made. Young persons should not attempt this experiment by themselves.

leaf be melted by the electric fluid? — Explain the structure and uses of the universal discharger. — By what electric means can a piece of paper be torn in pieces?—Can gunpowder be inflamed by the electric fluid? — How is wire fused by electricity?—How is it known that the superabundant electricity of the inside of the electric jar passes to the outside?—Can wood be rent asunder by electricity? — Explain the reason of the twelfth experiment.

CONVERSATION X.

OF THE ELECTRIC SPARK, AND MISCELLANEOUS EXPERIMENTS.

Father. I wish you to observe some facts connected with the electric spark. By means of the wire inserted in this ball, I fix it to the end of the conductor, and bring either another brass ball, or my knuckle to it, and if the machine act pretty powerfully, a long, crooked, brilliant spark will pass between the two balls, or between the knuckle and ball. If the conductor is negative, it receives the spark from the body; but if it is positive, the ball or the knuckle receives the spark from the conductor.

Ch. Does the size of the spark depend at all on the size of the conductor?

Fa. The longest and most vivid sparks are obtained from a large conductor, provided the machine acts very powerfully, or from between two conductors of a rounded form, in proportion as they are both portions of spheres of large diameter. When the quantity of electricity is small, the spark is straight; but when it is strong, and capable of striking at a greater distance, it passes through a considerable extent of air, and is of very great length, having the appearance of a long streak of fire, extending from the conductor to the ball, distributed in its direction to various points of the surface of the ball; and often assuming what is called a zig-zag direction.

Ja. If the electric fluid is fire, why does not the spark, which excites a painful sensation, burn me, when I receive it on my hand?

Fa. Ex. I.—I have shown you that the charge from a battery will make iron wire red hot, and set fire to gunpowder. Now stand on the glass-legged stool, and hold the chain from the conductor with one hand. You, Charles, must hold this spoon, which contains some spirits of wine, towards your

brother, while I turn the machine; and a spark taken from his knuckle, if sufficiently large, will set fire to the spirit.

Ch. It has, indeed! Did you prepare the spirit for the purpose?

Fa. I merely made the silver spoon tolerably warm before I put the spirit into it.

Ex. II.—If a ball of box-wood be placed on the conductor, instead of the brass ball, a spark taken from it will be of a fine red colour.

Ex. III.—An ivory ball placed on the conductor will assume a very beautiful and luminous appearance if a strong spark be taken through its centre.

Ex. IV.—Sparks taken over a piece of silvered leather appear of a green colour, and over gilt leather of a red colour.

Ex. V.—Here is a glass tube, round which, at small distances from each other, pieces of tin-foil are pasted, in a spiral form, from end to end: this tube is enclosed in a larger one, fitted with brass caps at each end, which are connected with the tin-foil of the inner tube. Now shut the window-shutters. I will hold one end, A, in my hand, while one of you turn the machine, and I will apply the other end, B, to the conductor, from which it will take numerous sparks.

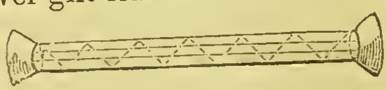
A  B

Fig. 13.

Ch. This is a very beautiful experiment.

Fa. The beauty of it consists in the distance remaining between the pieces of tin-foil; and were you to increase the number of these distances, the brilliancy would be very much heightened.

Ex. VI.—The following is another experiment of the same kind. Here is a word, with which you are acquainted, imprinted on glass, by means of tin-foil pasted on it, and fixed in a frame of baked wood. I will hold the frame in my hand at H, and present the ball G to the conductor; and at every considerable spark the word will be beautifully illuminated.

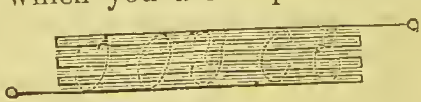


Fig. 14.

Ex. VII.—A piece of sponge filled with water, and hung to a conductor, when electrified in a dark room, exhibits also a beautiful appearance.

Ex. VIII.—This bottle is now charged. If I bring the

brass knob projecting from it to a basin of water which is insulated, it will attract a drop of the liquid; and this, on the removal of the bottle, will assume a conical shape; and if brought near any conducting substance, it will dart to it in luminous streams.

Ex. IX.—Place a drop of water on the conductor, and work the machine, the drop will afford a long spark, assume a conical figure, and carry some of the water with it.

Ex. X.—On this wire I have fixed a piece of sealing-wax, and when I have fixed the wire into the end of the conductor, I will light the wax, which, immediately the machine is worked, will fly off in extremely fine threads.

Ex. XI.—I will now wrap some cotton-wool round one of the knobs of the discharging rod, and fill the wool with finely-bruised resin; I will discharge a Leyden jar, or a battery, in the common way, and the wool you will perceive instantly in a blaze. The covered knob must touch the knob of the jar, and the discharge be effected as quickly as possible.

You will remember, that the electric fluid always takes the nearest direction and the best conductors to lead its course; in proof of which take the following experiment:—

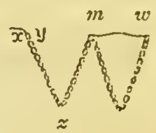


Fig. 15.

Ex. XII.—With this chain make a sort of W, let the wire *w* touch the outside of a charged jar, and the wire *x* be brought to the knob of the jar; if you are in the dark you will observe a brilliant W. But if the wire *w* is continued to *m*, the electric fluid will take a shorter direction to *x*, and, of course, only half of the W will be seen,—viz., that part marked *mzy:* but if, instead of the wire *wm*, a dry stick be employed, the electric matter will take a longer circuit, rather than go through a bad conductor, and the whole W will be illuminated.

Ex. XIII.—Here is a two-ounce phial half full of salad oil: through the cork is passed a piece of slender wire, the end of which, within the phial, is so bent as to touch the glass just below the surface of the oil. I will now place my thumb opposite the point of the wire in the bottle, and in that position take a spark from the charged conductor. You may observe that the spark, in order to get to my thumb, has actually perforated the glass. In the same way I can make perforations all round the phial.

Ch. Would the experiment succeed with water instead of oil?

Fa. No; it would not.

Ja. At any rate, we see the course of the electric fluid in this experiment: for the spark comes from the conductor down the wire, and through the glass to the thumb.

Fa. Its direction is, however, better shown in this way:—

Ex. XIV.—At that end of the conductor which is farthest from the machine, fix a brass wire about six inches long, having a small brass ball on its extremity. To this ball, when the machine is at work, hold the flame of a wax taper.

Ch. The flame is evidently blown from the ball in the direction of the electric fluid: and it has a similar effect to the blast of a pair of bellows.

Ex. XV.—Fix a pointed wire upon the prime conductor, with the point outward, and a similar wire upon the insulated rubber. — Shut the window-shutter, and work the machine.—Now observe the points of the two wires.

Ja. They are both illuminated, but differently. The point on the conductor sends out a kind of brush of fire; but that on the rubber has the appearance of an illuminated star.

Fa. You see now, then, I hope, the difference between positive and negative electricity.

QUESTIONS FOR EXAMINATION.

Does the size of the electric spark depend on the conductor? — What reasons are there for supposing that the electric fluid partakes of the nature of fire? — Is the spark different according to the substance from which it is taken? — How is an ivory ball made luminous? — Explain the experiment of the spiral tube.— Upon what does its brilliancy depend? — What appearances are exhibited by a wet sponge attached to a conductor? — What effect has the electric fluid on a drop of water? — What is the experiment with sealing-wax? — How is cotton-wool set on fire? — What course does the electric fluid always take? — Explain this by fig. 15. — How is a hole made through a glass phial? — How is the course of the fluid shown with a lighted taper?—Explain the difference between the positive and negative electricity.

CONVERSATION XI.

MISCELLANEOUS EXPERIMENTS — OF THE ELECTROPHORUS — OF THE ELECTROMETER, AND THE THUNDER HOUSE.

Father. I shall proceed this morning with some other experiments on the electrical machine.

Ex. I.—Here are two wires; one of which is connected with the outside of a charged Leyden jar; the other is so bent as to touch the knob of the jar. The two straight ends I will bring within the tenth of an inch of each other, and press them down with my thumb; and having darkened the room, in this position I will discharge the jar. Now look at my thumb.

Ch. It was so transparent that I think I even saw the bone of it. Did it not hurt you very much, Papa?

Fa. With attention, you might have observed the principal blood vessels, I believe; and the only inconvenience that I felt was a sort of tremor in my thumb, by no means painful. Had the wires been at double the distance, the shock would probably have passed round my thumb, which must have caused a more unpleasant sensation; but as I was so close, the electric fluid leaped from one wire to the other, and during its passage illuminated my thumb, without going through it.

Ex. II.—If, instead of my thumb, a decanter full of water, having a flat bottom, were placed on the wires, and the discharge then made, the whole of the water would have been beautifully illuminated.

Ex. III.—This small pewter bucket is full of water; suspend it from the prime conductor, and put in a glass syphon, with a bore so narrow, that the water will hardly drop out. After having darkened the room, observe what will happen when I work the machine.

Ja. It runs in a full stream, or rather in several streams; all of which are beautifully illuminated.

Fa. Ex. IV.—If the knob *a* communicate with the outside of a charged Leyden jar, and the knob *b* with the outside coating, and each be held about two inches from the lighted candle *x*, and opposite to each other, the flame will spread towards each, and a discharge be made through it: this shows the conducting power of flame.

Fig. 16.

This instrument, which consists of two circular plates, of which the largest, B, is about fifteen inches in diameter, and the other, A, fourteen inches, is called an *electrophorus*. It was invented about the year 1774, by Professor Volta, a name well known from his numerous discoveries in electrical science.

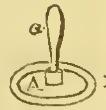


Fig. 17.

It takes its name from the Greek *electron* (ἤλεκτρον), and *phero* (φερω), "I bear or carry." The *under* plate, B, is made of glass, sulphur, pitch, or sealing-wax, or of any other non-conducting substance, such as a mixture of pitch and chalk boiled together. The upper plate, A, called the cover, is sometimes made of brass, and sometimes of tin; but this is of wood, covered very neatly with tin-foil, and well rounded at the edges, to prevent the dispersion of the electricity: *a* is an insulating handle of glass, fixed to a socket, by which the upper plate is removed from the under one.

Ch. What do you mean by an electrophorus?

Fa. It is, in fact, a sort of simple electrical machine, and is thus used. Rub the upper surface of the lower plate, B, with a fine piece of new flannel, or fur, and when it is well excited, and brought into a state negatively electrical, place upon it the upper plate, A, by the insulating handle, and then put your finger on the upper plate; next remove this plate by the glass handle, *a*, and if you apply your knuckle, or any other conductor communicating with the earth, or the knob of a coated jar, you will obtain a spark. This operation may be repeated many times without exciting again the under plate; it will also inflame a jet of hydrogen gas.

Ja. Can you charge a Leyden jar in this way?

Fa. Yes; it has been done, and by a single excitation, so as to pierce a hole through a card.

Here is an electrometer, which is far superior to any yet invented; as it is capable of discovering the smallest quantities of electricity. A is a glass jar, B the cover of metal, to which are attached two pieces of gold leaf *x*, or two pith balls suspended on threads. On the sides of the glass jar are two narrow strips of tin-foil.

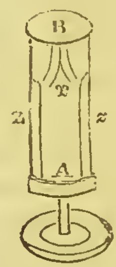


Fig. 18.

Ch. How is this instrument used?

Fa. Anything that is electrified is to be brought to the cover, which will cause the pieces of gold leaf, or pith balls, to diverge; and the sensibility of this instrument is so great, that the brush of a feather, the throwing of chalk, hair-powder, or dust, against the cap B, evinces strong signs of electricity.

Ex. V.—Place on the cap B a little pewter, or any other metallic cup, having some water in it; then take from the fire

a live cinder, and put it in the cup, and the electricity of vapour is very admirably exhibited.

A thunder cloud passing over this instrument will cause the gold leaf to strike the sides at every flash of lightning.

Ex. VI.—Excite this stick of sealing-wax, and bring it to the cover B. Now observe how often it causes the gold leaf to strike against the sides of the glass.

Ja. Are the slips of tin-foil intended to carry away the electric fluid communicated by the objects presented to the cap B?

Fa. They are; and by them the equilibrium is restored.

QUESTIONS FOR EXAMINATION.

How is the thumb illuminated by the electrical fluid, and what may be seen during the experiment? — How is water illuminated? — Explain the construction of an electrometer. — What is an electrophorus? — Show me the construction of a greatly improved electrometer, and how is it used? — How is electricity shown by evaporation?

CONVERSATION XII.

OF ATMOSPHERIC ELECTRICITY.

Charles. You said yesterday, that the electrometer was affected by thunder and lightning. Are lightning and electricity similar?

Fa. They are undoubtedly the same fluid, as was discovered by Dr. Franklin more than half a century ago.

Ja. How did he ascertain this fact?

Fa. He was led to its theory from observing the power which uninsulated *points* possess of drawing from bodies their electricity. While waiting for the erection of a spire in Philadelphia, to carry his ideas into execution, it occurred to him that a boy's kite would answer his purpose better than a spire. He therefore prepared a kite, and, having raised it, he tied to the end of the string a silken cord, by which he might make the kite completely insulated. At the junction of the two strings he fastened a key, as a good conductor, in order to take sparks from it.

Ch. Did he obtain any sparks?

Fa. One cloud, which appeared like a thunder-cloud, passed

without any effect. Shortly after, the loose threads of the hempen string stood erect, in the same manner as they would if the string had been hung on an electrified insulated conductor. He then presented his knuckle to the key, and obtained an evident spark. Others succeeded; but when the rain had wetted the string, he collected the electricity very plentifully.

Ja. Could I do so with our large kite?

Fa. I should not like you to raise your kite during a thunder-storm, because, without very great care, it might be attended with considerable danger. A celebrated electrician, Professor Richman, of St. Petersburg, was struck dead by a flash of lightning, which he had collected from the clouds, by a somewhat similar apparatus. Your kite is, however, quite large enough; for it is four feet high, and two feet wide; but everything depends on the string, which, according to Mr. Cavallo, who has made many experiments on the subject, should be made of two thin threads of twine, twisted with a copper thread. If you are desirous of raising kites, for electrical purposes, I must refer you to Mr. Cavallo's work on Electricity, vol. ii., in which you will find ample instruction.

Ch. How do those conductors, which I have seen fixed to various buildings, operate in dispersing lightning?

Fa. You know how easy it is to charge a Leyden jar: but when the machine is at work, if a person hold a point of steel, or other metal, near the conductor, the greater part of the fluid will run away by that point instead of proceeding to the jar. Hence it was concluded that pointed rods would draw away from buildings the lightning from clouds that were passing over them.

Ja. Is there not a particular method of fixing them?

Fa. Yes: the metallic rod must reach from the ground, or the nearest piece of water, to a foot or two above the building it is intended to protect, and should terminate in a fine point. Some electricians recommend that the point should be of gold, to prevent rusting.

Ch. What would be the consequence if lightning were to strike a building which was devoid of a conductor?

Fa. That may be best explained by telling you what happened, many years ago, to St. Bride's church. The lightning first struck the weather-cock: descending thence

the steeple in its progress, it beat out several large stones at different heights; some of which fell upon the roof of the church, and did great damage. The mischief done was so considerable, that it became necessary to take down eighty-five feet of the steeple to repair it.

Ja. The weather-cock was probably made of iron; if so, why did it not act as a conductor?

Fa. Although it was made of iron, yet it was completely insulated by being fixed in stone, which had become dry by continued hot weather. When, therefore, the lightning had struck the weather-cock, by endeavouring to force its way to another conductor, it beat down whatever opposed it.

Ch. The power of lightning must be very great.

Fa. It is irresistible. The following experiment will further illustrate it.

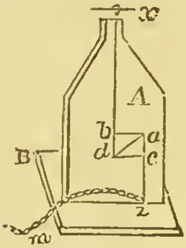


Fig. 19.

Ex. I.—A is a board representing the gable end of a house: it is fixed on another board B: *a b c d* is a square hole to which a piece of wood is fitted; *a d* represents a wire fixed diagonally on the wood *a b c d; x b*, terminated by a knob, *x*, represents a weather-cock, and the wire *c z* is fixed to the board A.

It is evident that in the state in which it is drawn in the figure, there is an interruption in the conducting rod; accordingly, if the chain *m* is connected with the outside of a Leyden phial, and that phial is discharged through *x*, by bringing one part of the discharging rod to the knob of the Leyden phial, and the other to within an inch or two of *x*, the piece of wood, *a b c d*, will be thrown out with violence.

Ja. Are we to understand by this experiment that if the wire *x b* had been continued to the chain, the electric fluid would have run along it without disturbing the loose board?

Fa. Ex. II.—Yes: for if the piece of wood be taken out, and the part *a* be put to the place *b*, then *d* will come to *c*, and the conducting rod will be complete, and continued from *x* through *a* and *d* to *z;* now the phial may be discharged as often as you please: but the wood will remain in its place, because the electric fluid runs over the wire to *z*, and makes its way by the chain to the outside of the phial.

Ch. Then if *x* represent the weather-cock of the church,

the lightning having overcharged it, by its endeavours to reach another conductor, as *c z*, has forced away the stone or stones represented by *a b c d*?

Fa. That is what I meant to convey to your minds by the first experiment; and the second illustration shows very clearly, that if an iron rod had gone from the weather-cock to the ground, without interruption, it would have conducted the electricity safely to the earth without doing any injury to the church.

Ja. How was it that all the stones were not beaten down?

Fa. Because, in its passage downwards, it met with many other conductors. I will read part of what Dr. Watson says on this fact, who examined it very attentively:—

"The lightning," says he, "first took a weather-cock, which was fixed at the top of the steeple, and was conducted without injuring the metal or anything else, as low as where the large iron bar or spindle which supported it terminated: there the metallic communication ceasing, part of the lightning exploded, cracked, and shattered the obelisk, which terminated the spire of the steeple, in its whole diameter, and threw off, at that place, several large pieces of Portland stone. Here it likewise removed a stone from its place, but not far enough to be thrown down. Thence the lightning seemed to have rushed upon two horizontal iron bars, which were placed within the building across each other. At the end of one of these iron bars, it exploded again, and threw off a considerable quantity of stone. Almost all the damage was done where the ends of the iron bars had been inserted into the stone, or placed under it; and, in some places, its passage might be traced from one iron bar to another."

QUESTIONS FOR EXAMINATION.

Who discovered that electricity and lightning were the same? — How was this ascertained? — Can lightning be obtained by a kite? — In what way do conductors save buildings from danger? — How are they formed? — What church has been injured by lightning? — Explain the structure of the thunder-house. — What do the experiments on it teach? — Give me some account of Dr. Watson's description of the injury done to St. Bride's church.

CONVERSATION XIII.

ON ATMOSPHERIC ELECTRICITY—OF THE AURORA BOREALIS—OF WATERSPOUTS AND WHIRLWINDS—OF EARTHQUAKES.

Charles. Does the air always contain electricity?

Fa. Yes; and it is owing to the electricity of the atmosphere that we observe a number of curious and interesting phenomena, such as the Aurora Borealis, or Northern Lights; Water-spouts; Hail; the Ignis Fatuus, or Will-o'-the-wisp.

Ja. Since lofty objects are most exposed to the effects of lightning, or, as it is scientifically called, the electric fluid, do not the tall masts of ships run considerable risk of being struck by it?

Fa. Certainly: we have many instances recorded of the mischief done to ships by lightning: one of which is related in the Philosophical Transactions; it happened on board the Montague, on the 4th of November, 1748, in lat. 42° 48′, and 9° 3′ west longitude, about noon. The master of the vessel looked to windward, and observed a large ball of blue fire, rolling apparently on the surface of the water, at the distance of three miles from them: it rose almost perpendicularly when it was within forty or fifty yards of the ship, and then burst with an explosion, as if a hundred cannons had been fired at one time; it left so strong a smell of sulphur, that the ship seemed to contain nothing else. After the noise had subsided, the main-top-mast was found shattered to pieces, and the mast itself was split down to the keel. Five men were also knocked down, and one of them greatly burnt.

Ch. Must it not have been a very large ball to produce such effects?

Fa. Yes: the person who noticed it said it appeared to him the size of a millstone.

The aurora borealis is another electrical phenomenon: this is admitted without any hesitation, because electricians can readily imitate its appearance with their experiments.

Ja. It must be, I should think, on a very small scale.

Fa. True: there is a glass tube about thirty inches long, and the diameter of it is about two inches: it is nearly exhausted of air, and capped on both ends with brass. Connect

these ends, by means of a chain, with the positive and negative part of a machine, and, in a darkened room, you will see, when the machine is worked, all the appearances of the northern lights in the tube.

Ch. Why is it necessary nearly to exhaust the tube?

Fa. Because the air, in its natural state, is a very bad conductor of the electric fluid; but when it becomes considerably rarer than it generally is, the electric fluid darts from one cap to the other with the greatest velocity.

Ja. But we see the natural Aurora Borealis also in the air.

Fa. We do so; but it is in the higher regions of the atmosphere, where the air is much rarer than it is near the surface of the earth. The experiment which you have just seen accounts for the darting and undulating motion which takes place between the opposite parts of the heavens. The Aurora Borealis is most brilliant in those countries which are in the high northern latitudes, as in Greenland and Iceland.

The Aurora Borealis which was seen in this country on the 23rd of October, in the year 1804, is deserving of notice. At seven in the evening, a luminous arch was seen from the centre of London, extending from one point of the horizon, about S.S.W., to another point, N.N.W., and passing the middle of the constellation of the Great Bear, which it very much obscured. It appeared to consist of an illuminated vapour, rolling from South to North. In about half an hour its course was changed, and became vertical; and about nine o'clock, it extended across the heavens from N.E. to S.W.: at intervals, the continuity of the luminous arch was broken, and strong flashes and streaks of bright red, similar to those which appear in the atmosphere during a great fire in any part of the metropolis, darted from its South-West quarter, towards the zenith. For several hours the atmosphere was as light in the South-West as if the sun had not set more than half an hour; and the light in the North resembled the strong twilight which marks that part of the horizon at Midsummer.

Ja. How do you account, Papa, for the Will-o'-the-wisp, or Jack-o'-lantern, as it is sometimes called?

Fa. This is a meteor which seldom appears more than six feet above the ground: it is always about bogs and swampy places; which, in hot sultry weather, emit an inflammable air, which is easily set on fire by the electric spark. These also,

as you shall see in our chemical experiments, we can as readily imitate as the aurora borealis. In some parts of Italy, meteors of this kind are frequently very large, and give a light equal to that of a torch.

Water-spouts, too, which are sometimes seen at sea, are supposed to arise from the power of electricity.

Ch. I have heard of these; but I thought that water-spouts at sea, and whirlwinds and hurricanes by land, were produced solely by the force of the wind.

Fa. The wind is, undoubtedly, one of the causes; but it will not account for every appearance connected with them. Water-spouts are often seen in calm weather; the sea seems to boil, and send up a vapour which rises in the shape of a cone. A rumbling noise is often heard at the time of their appearance, which happens generally in those months that are peculiarly subject to thunder storms; and they are commonly accompanied by lightning.

The analogy between the phenomena of water-spouts and electricity may be made visible by hanging a drop of water to a wire, communicating with the prime conductor, and placing a vessel of water under it. In these circumstances, the drop assumes all the various appearances of a water-spout, in its rise, form, and mode of disappearing.

Water-spouts, at sea, are undoubtedly very like whirlwinds and hurricanes by land. These sometimes tear up trees, and throw down buildings, and scatter the earth, bricks, stones, timber, &c., to a great distance in every direction. Dr. Franklin mentions a remarkable appearance which occurred to Mr. Wilke, a distinguished electrician. On the 20th of July, 1758, at three o'clock in the afternoon, he observed a great quantity of dust rising from the ground, and covering a field and part of the town in which he then was. There was no wind, and the dust moved gently towards the East, where there appeared a great black cloud, which excited his apparatus to a very high degree of positive electricity. This cloud went towards the West; the dust followed it, and continued to rise higher and higher, till it composed a thick pillar, in the form of a sugar-loaf; and at length it seemed to be in contact with the cloud. At some distance from this, came another great cloud, with a long train of smaller ones, which electrified his apparatus negatively; and

when they came near the positive cloud, a flash of lightning was seen to dart through the cloud of dust; the negative clouds immediately spread and dissolved themselves in rain.

Ch. Is rain, then, an electrical phenomenon?

Fa. The most enlightened and best informed electricians consider rain, hail, and snow, among the effects produced by the electric fluid.

Ja. Do the negative and positive clouds act in the same manner as the outside and inside coatings of a charged Leyden jar?

Fa. Thunder-clouds frequently do nothing more than conduct or convey the electric matter from one part of the heavens to another.

Ch. Then they may be compared to the discharging rod?

Fa. And perhaps, like that, they are intended to restore the equilibrium between two places, one of which has too much, and the other too little of the electric fluid. The following is not an uncommon appearance. A dark cloud is observed to attract others to it, and, when grown to a considerable size, its lower surface swells in particular parts towards the earth. During the time that the cloud is thus forming, flashes of lightning dart from one part of it to the other, and often illuminate the whole mass; and small clouds are observed moving rapidly beneath it. When the cloud has acquired a sufficient extent, the lightning strikes the earth in two opposite places.

Ja. I wonder the discharge does not shake the earth, as the charge of a jar shakes anything through which it passes.

Fa. Every discharge of clouds may do this, although it is imperceptible to us.

Earthquakes are sometimes probably occasioned by vast discharges of the electric fluid: they happen most frequently in dry and hot countries, which are subject to lightning, and other electric phenomena; they are even foretold by the electric coruscations, and other appearances in the air, for some days preceding the event. They are usually accompanied by rain, and sometimes by the most dreadful thunder-storms.

QUESTIONS FOR EXAMINATION.

What atmospherical phenomena does electricity account for? — Are the masts of ships ever injured by lightning? — What is the *aurora borealis?* — How is it imitated?—What is the Jack-o'-lantern? — What is the cause of water-spouts? — How is the resemblance between water-spouts and electricity shown? — Upon what principles are rain, hail, and snow accounted for? — What intention do thunder-clouds answer, and to what may they be compared? — What are earthquakes?

CONVERSATION XIV.

MEDICAL ELECTRICITY.

Father. If you stand on the glass-legged stool, and hold the chain from the conductor while I work the machine a few minutes, your pulse will be increased; that is, it will beat more frequently than it did before. From this and other circumstances, physicians have applied electricity to the cure of many disorders: in some, their endeavours have been unavailing; in others, the success has been very complete.

Ch. Did they do nothing more than this?

Fa. Yes; in some cases they took sparks from their patients; in others they gave them shocks.

Ja. This would be no pleasant method of cure, if the shocks were violent.

Fa. You know that, by means of Lane's electrometer, described in our Seventh Conversation, (fig. 10,) the shock may be given as slightly as you please.

Ch. But how are shocks conveyed through any part of the body?

Fa. There are machines and apparatus made expressly for medical purposes; but every result may be obtained by the instrument just referred to. Suppose the electrometer to be fixed to a Leyden phial, and the knob at A to touch the conductor, and the knob B placed nearer or more remote, according as it is intended that the shocks shall be weak or strong; one chain or wire is to be fixed to the ring C of the electrometer, and another to the outside coating: the remaining ends of these two wires are to be fastened to the two knobs of the discharging rod.

Ja. What next is to be done; if, for instance, I wish to electrify my knee?

Fa. All you have to do is to bring the balls of the dis

charging rod close to your knee, one on the one side, and the other on the opposite.

Ch. And at every discharge of the Leyden jar, the superabundant electricity from withinside will pass from the knob at A to the knob B, and will proceed by the wire and the knee, in its way to the outside of the jar, to restore to both sides an equilibrium.

Ja. But if it happen that the arm is to be electrified, how is that to be done? Because, in this case, I cannot use both hands in conducting the wires.

Fa. Then you must procure the assistance of a friend, who will be able, by means of two instruments, called *directors,* to conduct the fluid to any part of the body.

Ch. What are directors?

Fa. A director consists of a knobbed brass wire, which, by means of a brass cap, is cemented to a glass handle. The operator, holding these directors by the extremities of the glass handle, brings the balls, to which the wires or chains are attached, into contact with the extremities of that part of the body of the patient through which the shock is to be sent. If I feel rheumatic pains between my elbow and wrist, and a person hold one director at the elbow, and another at the wrist, the shocks will pass through, and probably will remove the complaint.

Ja. Is it necessary to stand on the glass-footed stool to have this operation performed?

Fa. By no means. When shocks are administered, the person who receives them may stand as he pleases, either on the stool or on the ground: the electric fluid, taking the nearest passage, will always reach the other knob of the other director, which leads to the outside of the jar.

Ch. Is it necessary to divest the body of its dress?

Fa. Not in the case of shocks, unless the clothing be very thick: but when sparks are to be taken, then the person from whom they are drawn must be insulated, and the clothes be taken off the part affected.

Ja. For what disorders are the shocks and sparks chiefly used?

Fa. They have been found useful in paralytic disorders; in contractions of the muscles; in sprains, and in other cases; but great attention is necessary in regulating the force of the shock; because, instead of advantage, mischief may occur if it be too violent.

Ch. Is there less danger with sparks?

Fa. Yes: for unless it be in very tender parts, as the eye, there is no great risk in taking sparks: and they have proved very effectual in removing many complaints.

The celebrated Mr. Ferguson was seized, at Bristol, with a violent sore throat, so as to prevent him from swallowing anything: he caused sparks to be taken from the part affected, and in the course of an hour he could eat and drink without pain.

This is an excellent method in some cases of deafness, earache, toothache, &c.

Ja. Would not strong sparks injure the ear?

Fa. They might; and therefore the electric fluid is usually drawn with a pointed piece of wood connected with the prime conductor, to delicate parts, on which it comes in a gentle stream; or, when sparks are taken, a very small brass ball is used at some distance from the body; because, in proportion to the size and distance of the ball, is the size and intensity of the spark.

QUESTIONS FOR EXAMINATION.

Has electricity been applied to any important purposes?—In medicine can the shock be regulated and passed through any part of the body?—Explain the mode of operation.—What are the directors? — Is it necessary that a person should be insulated to receive a shock? — For what disorders are shocks and sparks chiefly used? — How is electricity applied to the ear?

CONVERSATION XV.

OF ANIMAL ELECTRICITY—OF THE TORPEDO—OF THE GYMNOTUS ELECTRICUS—AND OF THE SILURUS ELECTRICUS.

Father. There are certain kinds of fish which have been found to possess the singular property of giving shocks very similar to those experienced by means of the Leyden jar.

Ch. I should like much to see them. Are they easily obtained?

Fa. No; they are not: they are called the *Torpedo,* the *Gymnotus electricus,* the *Silurus electricus,* the *Trichiurus Indicus,* and the *Tetraodon electricus.*

Ja. Are they all of the same genus?

Fa. No: the torpedo is a flat fish, a species of ray, seldom found twenty inches long, and common in various parts of the sea-coast of Europe. The electric organs of this fish are placed on each side of the gills, where they fill up the whole thickness of the animal, from the lower to the upper surface, and are covered by the common skin of the body: they are composed of a great multitude of vertical and parallel membranous plates, arranged in longitudinal columns of various forms, and intersected by a loose net-work of tendinous fibres, which bind them together: in the midst of these, however, are many interstices containing some kind of fluid, and the whole is well supplied with blood-vessels and nerves. It has been observed that the arrangement of these membranous plates has a very great resemblance to a voltaic battery, but whence the electrical properties are immediately derived is not known.

Ch. Can you lay hold of the fish by any other part of the body with impunity?

Fa. Not altogether so: for if it be touched with one hand, it generally communicates a very slight shock; but if it be touched with both hands at the same time, one being applied to the under, and the other to the upper surface of the body, a shock will be received similar to that which is occasioned by the Leyden jar.

Ja. Will not the shock be felt, if both hands be put on one of the electrical organs at the same time?

Fa. No: and this shows that the upper and lower surfaces of the electric organs are in opposite states of electricity, answering to the positive and negative sides of a Leyden phial.

Ch. Are the same substances conductors of the electric power of the torpedo, by which artificial electricity is conducted?

Fa. Yes, they are: and if the fish, instead of being touched by the hands, be touched by conducting substances, as metals, the shock will be communicated through them. The circuit may also be formed by several persons joining hands; and the shock will be felt by them all at the same time. But the shock will not pass where there is the smallest interruption: it will not even be conducted through a chain.

Ja. Can you get sparks from it?

Fa. No spark was ever obtained from the torpedo; nor could electric repulsion and attraction be produced by it.

Ch. Is it known how the power is accumulated?

Fa. It has been thought to depend on the will of the animal; for each effort is accompanied by a depression of its eyes; and probably it makes use of it as a means of self-defence.

Ja. Is this the case also with the other electrical fishes?

Fa. The *gymnotus* possesses all the electric properties of the torpedo, but in a very superior degree. This fish has been called the *electrical eel*, on account of its resemblance to the common eel. It is found in the large rivers of South America.

Ch. Are these fishes able to injure other fishes by this power?

Fa. If small fishes are put into the water in which the gymnotus is kept, it will first stun, or perhaps kill them, and if hungry, it will then devour them. But fishes stunned by the gymnotus may be recovered by speedily removing them into another vessel of water.

The gymnotus is said to be possessed of a kind of sense, by which it knows whether bodies which are brought near him are conductors or not.

Ch. Then it possesses the same knowledge by instinct which philosophers have gained by experiment.

Fa. The following experiment, among others, is very decisive on this point.

Ex. The extremities of two wires were dipped into the water of the vessel in which the eel was kept; they were then bent, extended a great way, and terminated in two separate glasses full of water. These wires being supported by non-conductors, at a considerable distance from each other, the circuit was incomplete: but if a person put the fingers of both hands into the glasses in which the wires terminated, then the circuit was complete. While the circuit was incomplete, the fish never went near the extremities of the wires, as if desirous of giving the shock; but the moment the circuit was completed, either by a person, or any other conductor, the gymnotus immediately went towards the wires, and gave the shock, though the completion of the circuit was out of his sight.

Ja. How do they catch this kind of fish? The men would probably let them go on receiving the shock.

Fa. The gymnotus, as well as the others, may be touched, without any risk of the shock, with wax or with glass; but if it be touched with the naked finger, a gold ring, or metal of any kind, the shock is felt completely up the arm.

Ch. Does the *Silurus electricus* produce the same effects as the other fish you have been describing?

Fa. This fish is found in some rivers in Africa; and it is known to possess the property of giving the electric shock; but no other particulars have been recorded respecting it.

With regard to the torpedo, its power of giving the benumbing sensation was known to the ancients; and from this it probably took its name. In Fermin's Natural History of Surinam is some account of the *trembling eel,* which Dr. Priestley conjectures to be a different fish from the gymnotus. It lives in marshy places, whence it cannot be taken, except when it is intoxicated. It cannot be touched with the hand, or with a stick, without feeling a powerful shock: even if trod upon with shoes, the legs and thighs are affected in a similar manner.

QUESTIONS FOR EXAMINATION.

How many species of fish show signs of electricity, and what are their names? — How is the torpedo described? — How is the shock received from this fish? — Are the opposite electricities shown by this fish? — Do the same substances conduct the electricity of the torpedo, by which artificial electricity is conducted? — Does this fish give out the electrical spark, or exhibit the effects of attraction and repulsion? — Does the power seem to depend on the will of the animal? — Does the gymnotus possess similar properties to those of the torpedo? — How does the gymnotus act upon other fish? — What is peculiar to this fish? — Mention the experiment on this subject. — How was the property of this fish discovered? — Is there much known of the *Silurus electricus?*

CONVERSATION XVI.

GENERAL SUMMARY OF ELECTRICITY, WITH EXPERIMENTS.

Father. Do you now understand what electricity is?

Ch. Yes; it is a fluid which seems to pervade all substances; and when undisturbed, it remains in a state of equilibrium.

Ja. And that certain portion which every body is supposed to contain is called the natural share of that body.

Fa. When a body is possessed of more, or less, than its natural share, it is said to be *charged* or electrified.

Ch. If it possess more than its natural share, it is said to be *positively* electrified; but if it contain less than its natural share, it is said to be *negatively* electrified.

Fa. What is the distinction between conductors and non-conductors of electricity?

Ch. The electric fluid passes freely through the *former;* but the *latter* oppose its passage.

Fa. You know that electricity is excited in the greatest quantities by the rubbing of conducting and non-conducting substances against each other.

Ex. Rub two pieces of sealing-wax or two pieces of glass together, and only a very small portion of electricity can be obtained: therefore the rubber of a machine should be a conducting substance, and not insulated.

Every electrical machine, with an insulated rubber, will act in three different ways: the rubber will produce *negative* electricity; the conductor will give out *positive* electricity; and it will communicate both powers at once to a person or substance placed between two directors connected with them.

Ja. How does the rubber produce negative electricity?

Fa. If you stand on a glass-legged stool, or upon any other non-conducting substance, and lay hold of the rubber, or a chain communicating with it, the working of the machine will take away from you a quantity of your natural electricity, therefore you will be negatively electrified.

Ch. Will this appear by the nature of the electric fluid, if I hold in my hand a steel point, as a needle?

Fa. If you, while standing on a non-conducting substance, are connected with the rubber, and your brother, in a similar situation, is connected with the conductor, then hold points in your hands, and I, while standing on the ground, first present a brass ball, or other substance, to the needle in your hand, and then to that in his hand, the appearance of the fluid will be different in both cases ; at the needle in your hand it will appear like a star, but at that in your brother's it will be rather in the form of a brush.—What will happen

if you bring two bodies near to each other which are both electrified?

Ja. If they are both positively or both negatively electrified, they will repel each other; but if one is negative and the other positive, they will attract each other till they touch, and the equilibrium is again restored.

Fa. If a body, containing only its natural share of electricity, be brought near to another that is electrified, what will be the consequence?

Ch. A quantity of electricity will force itself through the air in the form of a spark.

Fa. When two bodies approach each other, one electrified positively and the other negatively, the superabundant electricity rushes violently from one to the other, to restore the equilibrium. What will happen if your body, or any part of it, form part of the circuit?

Ja. It will produce an electric shock; and if, instead of one person alone, many join hands, and form a part of the circuit, they will all receive a shock at one and the same instant.

Fa. If I throw a larger quantity of electricity than its natural share on one side of a piece of glass, what will happen to the other side?

Ch. The other side will become negatively electrified: that is, it will have as much less than its natural share as the other has more than its natural share.

Fa. Does electricity, communicated to glass, spread over the whole surface?

Ja. No: glass being an excellent non-conductor, the electric fluid will be confined to the part on which it is thrown: and for that reason, and in order to apply it to the whole surface, the glass is covered with tin-foil, which is called a *coating.*

Fa. And if a conducting communication be made between both sides of the glass, what takes place then?

Ch. A discharge; and this happens whether the glass be flat, or of any other form.

Fa. What do you call a cylindrical glass vessel thus coated for electrical purposes?

Ja. A Leyden jar; and when the insides, and also the outsides of several of these jars are connected, it is called an electrical battery.

Fa. Electricity, in this form, is capable of producing the most powerful effects; such as melting metals, firing spirits, and other inflammable substances.—What effect has metallic points on electricity?

Ch. They discharge it silently, and hence their great utility in defending buildings from the dangerous effects of lightning.—Pray what is thunder?

Fa. As lightning appears to be the rapid motion of vast masses of electric matter, so thunder is the noise produced by the motion of lightning: and when electricity passes through the higher parts of the atmosphere, where the air is very much rarefied, it constitutes the aurora borealis.

Ex. If two sharp pointed wires be bent with the four ends at right angles, but pointing different ways, and they be made to turn upon a wire, *x*, fixed on the conductor, the moment it is electrified, a flame will be seen at the points *a b c d*; the wire will begin to turn round in the direction opposite to that to which the points are turned, and the motion will become very rapid.

Fig. 20.

If the figures of horses, cut in paper, be fastened upon these wires, the horses will seem to pursue one another, and this is called the electrical horse-race. Of course, upon this principle, many other amusing and very beautiful experiments may be made: and likewise several electrical orreries have been contrived, showing the motions of the earth and moon, and planets round the sun.

Ja. How do you account for this?

Fa. Fix a sharp pointed wire into the end of the large conductor, and hold your hand near it:—no sparks will ensue; but a cold blast will come from the point, which will turn any light wheels, mills, &c.

Ch. Can the direction in which the electric matter moves be distinguished by the senses?

Fa. The hypothesis most generally admitted on this subject is, that electricity is a uniform fluid, capable of being rarefied or condensed, and that in the common electrical machine it passes from the cylinder to the conductor with points.

Ch. On what principles is this hypothesis founded?

Fa. The most prevailing opinion is that if the conductor,

which derives its electricity from the cylinder, be made sharp or angular at any part, not very near the cylinder, a diverging cone of electric light will be *seen*, the vertex of which is the point itself; and the electric phenomena will be much diminished. But the conductor which is connected with the rubber, though its effects be equally diminished by a similar circumstance, will never exhibit the cone of rays, but is only tipped at the point with a small globular body of light. The cone has been thought to resemble the rushing out or emitting of light, and the globe the appearance of the imbibing or entrance of the electric matter. And hence the term *positive* electricity has been adopted for that of the cylinder, and *negative* for that of the rubber.

Ch. And are these terms universally adopted in that sense?

Fa. I have so used them in the experiments mentioned in our Conversations; but I perceive that some writers are doubtful of the propriety of this application.

Ja. If electricity be produced by the excitation of a globe or cylinder of sulphur or resin, will the same terms apply?

Fa. No: in that case they will be reversed; the rubber will be positive, and the cylinder, with its conductor, will be negative.

The difference in most cases, it is said, arises from the relative smoothness of the surfaces of the electric body and its rubber when compared with each other. Glass, made rough by grinding with emery, excited by flannel, is *negative;* but with dry oiled silk, rubbed with whiting, it is positive. Even polished glass may be rendered negative, according to the same authority, by rubbing it with the hairy side of a cat's skin.*

Ch. Is air perfectly electric?

Fa. It must not be understood to be perfectly so, but composed of non-conducting parts. It is only permeable by the force of the electric fluid which divides it, or separates its parts. When this happens to a solid electric, a hole is made through it. Long sparks from a machine are all always crooked in various directions, like lightning; which effect seems to be caused by the electric matter passing through those parts of the air in which the best conductors are found.

* Nicholson, Nat. Phil.

In respect of the electric matter, it seems that its distribution is general; that its presence (as discovered by proper conductors) is perpetual; that it appears to be in constant motion, scarcely maintaining a state of rest for even an hour; that all objects have their share of it; that objects affect it even from a distance; that when objects have too little of it, they attract a quantity from those which have too much, in order to maintain an equality; that it seems necessary to vitality; that it is capable of being collected in very large quantities; that then it may be made to perform most, if not all, the operations of common fire; and that, when collected in quantities, it is capable of irresistible effects; such as lightning, earthquakes, &c.

Ch. What is the difference between Magnetism and Electricity, Papa?

Fa. As to Magnetism, it has of late years been found that it is so closely allied to Electricity, that the one never operates without the other, and that there is no possibility of determining what part it takes in the connexion.

SOME OF THE LEADING DEFINITIONS EXPLAINED AND ILLUSTRATED, WHICH IT IS RECOMMENDED THAT THE PUPILS SHOULD COMMIT TO MEMORY.

ELECTRICITY

1. The electric fluid is supposed to pervade almost all substances, and when undisturbed it remains in a state of equilibrium.

2. That portion which every substance is supposed to contain is called its natural share.

3. Its properties were first observed in amber, by Thales, six hundred years before the birth of Christ.

4. They were noticed in the tourmaline by Theophrastus.

5. Mr. Boyle is supposed to have been the first person who saw the electric ht.

6. Sir Isaac Newton first observed the electrical attractions of excited glass.

7. Bodies through which the electric fluid passes freely are called conductors.

8. Those which oppose the passage of electricity are called electrics.

9. When a body possesses *more* or *less* than its natural share of the electric fluid, it is said to be electrified or charged.. In the former case it is said to be positively electrified, in the latter it is said to be negatively electrified.

10. Electricity is excited in the greatest quantities by the friction of conductors and electrics against each other.

11. A body prevented from touching the earth, or communicating with it by means of glass, or other non-conducting substances, is said to be insulated.

12. Two bodies both positively or both negatively electrified repel each other.

13. If, of two bodies electrified, the one be electrified positively and the other negatively, they will attract each other.

14. Upon the principle of attraction and repulsion electrometers are formed.

15. If a body containing only its natural share of electricity be presented sufficiently near to a body electrified either plus or minus, a quantity of the electric fluid will pass from the latter to the former in the shape of a spark.

16. When two electrified bodies, one plus and the other minus, approach each other sufficiently near, the superabundant electricity rushes violently from one to the other to restore the equilibrium.

17. If an animal be so placed as to form part of this circuit, the electricity, in passing, produces a certain effect, called an electric shock.

18. The motion of the electric fluid in passing from a positive to a negative body is so rapid, that it appears to be instantaneous.

19. When the outside of a glass jar is presented to a body electrified plus, that side of the jar will be electrified minus: but the inside of the jar will be electrified plus, and vice versa.

20. The electric fluid communicated to glass does not spread, on account of the non-conducting quality of glass.

21. Electrical, or, as they are usually called, Leyden jars are partly covered with tin-foil and partly bare: the tin-foil accelerates the communication of the electric fluid, and the bare part of the jar prevents it from passing from the one side to the other. A jar so covered is said to be coated.

22. If a communication by a conducting substance be made between the inside and outside of a coated and charged jar, a discharge takes place.

23. Several Leyden jars connected together both with respect to the insides and outsides are called an electrical battery.

24. Electricity by means of a battery is capable of firing inflammable substances; of fusing some metals, of oxidating others, and even of killing small animals.

25. Metallic points attract the electric fluid from bodies, and discharge them silently: hence the use of conductors in preserving buildings from the effects of lightning.

26. When electricity enters a point, it appears in the form of a star; when it issues from a point, it puts on the form of a brush.

27. It is demonstrated that lightning and the electric fluid are identical.

28. Lightning may be drawn from the clouds by a common kite.

29. Thunder is the noise produced by the motion of lightning.

30. When the electric fluid passes through highly rarefied air, it constitutes the aurora borealis: this phenomenon may be imitated by experiment.

31. Earthquakes, whirlwinds, and water-spouts are probably the effects of electrical agency.

32. The electric fluid has been applied with great success to many medical cases.

33. There are several fish that exhibit strong electrical powers.

GALVANISM.

CONVERSATION I.

OF GALVANISM.

Father. It has been observed, as long as I can remember, and probably before I was born, that porter, when drunk from a pewter vessel, had a better flavour than when drunk out of glass or china.

Ch. Yes; I have often heard my uncle say so: but what is the reason of it?

Fa. Admitting the fact, which is, I believe, generally allowed by those who are much accustomed to that beverage; it is now explained upon the principle of *Galvanism.*

Ja. Is Galvanism another branch of science? Is there a Galvanic fluid as well as an electric fluid?

Fa. Of the existence of the electric fluid you now have no doubt: the science of electricity took its name from *electron*, the Greek word for amber, as I have before told you; because amber was one of the first substances observed to produce, by rubbing, the effects of attraction and repulsion. Galvanism derives its name from Dr. Galvani, a professor of anatomy at Bologna, who first reported to the philosophical world, in 1798, the experiments on which the science is founded.

Ch. Pray how was he led to make the experiments?

Fa. Galvani was one evening making some electrical experiments; and on the table, where the machine stood, were some skinned frogs: by accident, one of the company touched the main nerve of a frog, at the same moment that he took a considerable spark from the conductor of the electrical machine; and the muscles of the frog were thrown into strong

convulsions. These, which were observed by Galvani's wife, led the professor to a number of experiments; but as they cannot be repeated without much cruelty to living animals, I shall not enter into a detail of them.

Ja. Were not the frogs dead which first led to the discovery?

Fa. Yes, they were: but the professor afterwards made many experiments upon living ones; whence he found that the onvulsions, or, as they are usually called, the contractions, produced on the frog, may be excited without the aid of any apparent electricity, merely by making a communication between the nerves and the muscles with substances that are *conductors* of electricity.

Ch. Are these experiments peculiar to frogs?

Fa. No, they have been successfully made on almost all kinds of animals, from the ox to the fly. And hence it was at first concluded that there was an electricity peculiar to animals.

Ja. You have already shown that the electric fluid exists in our bodies, and may be taken from them, independently of that which causes the contractions.

Fa. I will show you an experiment on this subject. Here is a thin piece of *zinc*, which is a metallic substance: lay it *under* your tongue, and lay this half-crown *upon* the tongue. Do you taste anything very peculiar in the metals?

Ja. No, nothing at all.

Fa. Put them in the same position again, and now bring the edges of the two metals into contact.

Ja. Now they excite a very disagreeable taste, something like copperas.

Fa. Instead of the half-crown, try the experiment with a guinea, or with a piece of charcoal.

Ch. I perceive the same kind of taste which James described. How do you explain the fact?

Fa. Some philosophers maintain that the principle of Galvanism and Electricity is the same; and that the former is the evolution or emission of the electric fluid from *conducting* bodies, disengaged by a chemical process; while the latter is the same thing made apparent to the senses by *non-conducting* bodies.

Ja. All metals are conducting substances: of course the zinc, the guinea, and the half-crown are conductors.

Fa. Yes; and so are the tongue and the saliva: and it is probable that, by the decomposition of the saliva, the sharp taste is excited.

Ch. The disagreeable taste on the tongue cannot be disputed but there is no apparent change on the zinc or the half-crown, which there ought to be if a new substance, such as oxygen, has entered into the combination.

Fa. The change is, perhaps, too small to be perceived in this experiment; but in others, on a larger scale, it will be very evident to the sight, by the *oxidation* of the metals.

Ja. Here is another strange word. I do not know what is meant by oxidation.

Fa. The iron bars fixed before the window were clean and almost bright when placed there last summer.

Ja. But not having been painted, they are become quite rusty.

Fa. Now, in chemical language, the iron is said to be oxidated instead of rusty; and the earthy substance that may be scraped from them is denominated the oxide of iron.

When mercury loses its fine brightness by being long exposed to the air, the dulness is occasioned by oxidation; that is, the same effect is produced by the air on the mercury, as was on the iron. I will give you another instance. I will melt some lead in this ladle. You see a scum is speedily formed. I take it away, and another will arise, and so perpetually, till the whole lead is thus transformed into an apparently different substance. This is called the oxide of lead, and is formed by the union of the oxygen of the air with the melted metal.

QUESTIONS FOR EXAMINATION.

How is the fact explained, that porter is better tasted when drunk from pewter than glass? — Can you give some account of the rise and progress of Galvanism? — Can the experiments on Galvanism be made on animals generally? — What experiment is made with the zinc and silver? — Can it be made with other substances? — How is the principle of Galvanism explained? — What substances are those that conduct the Galvanic fluid? — How is the taste excited by Galvanism accounted for? — In this case what change does the metal undergo? — What do you mean by oxidation? — Illustrate this in the case of mercury and lead.

CONVERSATION II.

GALVANIC OR VOLTAIC LIGHT, AND SHOCKS.

Charles. We had a *taste* of the Galvanic fluid yesterday. Is there no way of seeing it?

Fa. Put this piece of zinc between the upper lip and the gums, as high as you can, and thenlay a half-crown or guinea upon the tongue, and, when so situated, bring the metals into contact.

Ch. I thought I saw a faint flash of light.

Fa. I dare say you did. It was for that purpose I wished you to make the experiment. It may be done in another way; by putting a piece of silver up one of the nostrils, and the zinc on the upper part of the tongue, and then bringing the metals in contact, the same effect will be produced.

Ja. By continuing the contact of the two metals, the appearance of light does not remain.

Fa. No; it is visible only at the moment of contact. You may, if you make the experiment with great attention, put a small slip of tin-foil over the ball of one eye, and hold a teaspoon in your mouth, and when the spoon and the tin come in contact a faint light will be visible. These experiments are best performed in the dark.

Ch. Are there no means of making experiments on a larger scale?

Fa. Yes; we have Galvanic batteries, as well as electrical batteries. Here is one of them. It consists of a number of pieces of silver, zinc, and flannel, of equal sizes, and they are thus arranged: — a piece of zinc, a piece of silver, and a piece of flannel, moistened with a solution of salt in water; and so on, till the pile is completed. To prevent the pieces from falling, they are supported on the sides by three rods of glass stuck into a piece of wood; and down these rods slides another piece of wood, which keeps all the pieces in close contact.

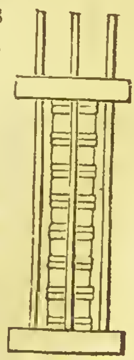


Fig. 1.

Ja. How do you make use of this instrument?

Fa. Touch the lower piece of metal with one hand, and the upper one with the other.

Ja. I felt an electric shock.

Fa. And you may take as many as you please; for as often as you renew the contact, so often will you feel the shock.

Here is a different apparatus. In these three glasses (and I might use twenty instead of three) is a solution of salt and water. Into each glass, except the two outer ones, is plunged a small plate of zinc, and another of silver. These plates are made to communicate with each other by means of a thin wire, fastened so that the silver of the first glass is connected with the zinc of the second; the silver of the second with the zinc of the third; and so on. Now, if you dip one hand into the first glass, and the other into the last, the shock will be felt.

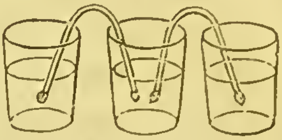


Fig. 2.

Ch. Will any kind of glasses answer for this experiment?

Fa. Yes: wine-glasses, or goblets, or finger-glasses; and even china cups.

A third kind of battery, which is very powerful, and the one that is very frequently used, is this:—It consists of a trough of baked wood, three inches deep, and about the same in breadth. In the sides of this trough are grooves opposite to

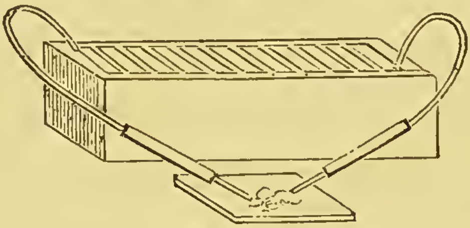


Fig. 3.

each other, and about a quarter of an inch asunder. Into each pair of these grooves is put a plate of zinc, and another of silver, which are cemented in such a manner as to prevent any communication between the different cells. The cells are now filled with a solution of salt and water, and the battery is complete. Now with your hands make a communication between the two end-cells.

Ch. I felt a strong shock.

Fa. Now wet your hands, and join your left with James's right hand; then put your right hand into a cell at one end, and let James put his left into the opposite one.

Ja. We both felt the shock like an electric shock, but not so severe.

Fa. Several persons may receive the shock together, by joining hands, if their hands are well moistened with water The strength of the shock is much diminished by passing through so long a circuit. The shock from a battery consisting of fifty or sixty pairs of zinc and silver, or zinc and copper, may be felt as high as the elbows. And if five or six such batteries be united with metal cramps, the combined force of the shock would be such that few would willingly take it a second time.

Ch. Of what use are the wires at each end of the trough?

Fa. With these a variety of experiments may be made upon combustible bodies. I will show you one with gunpowder: but I must have recourse to four troughs united by cramps, or to one much larger than this.

Towards the ends of the wires are two pieces of glass tubes. These are for the operator to hold by, while he directs the wires. Suppose, now, four or more troughs to be united, and the wire to be at the two extremities; I put some gunpowder on a piece of flat glass, and then holding the wires by the glass tubes, I bring the ends of them to the gunpowder; and, just before they touch, the gunpowder will be ignited.

Instead of gunpowder, gold and silver leaf may be burnt in this way: ether, spirits of wine, and other inflammable substances, are easily fired by the Galvanic battery, which will consume even small metallic wires.

Copper or brass leaf, commonly called Dutch gold, burns with a beautiful green light; silver with a pale blue light, and gold with a yellowish green light.

Ja. Will the battery continue to act any great length of time?

Fa. The action of all these kinds of batteries is the strongest when they are first filled with the fluid; and it declines in proportion as the metals are oxidated, or the fluid loses its power. Of course, after a certain time, the fluid must be changed and the metals cleaned, either with sand, or by immersing them for a short time in diluted muriatic acid. The best fluid to fill the cells with, is water mixed with one tenth of nitric acid. Care must always be taken to wipe quite dry the edges of the plates, to prevent a communication between the cells: and it will be found, that the energy of the battery is in proportion to the rapidity with which the zinc is oxidated.

Under the term Galvanism are often included the phenomena of the *Voltaic* battery.

QUESTIONS FOR EXAMINATION.

How can the Galvanic fluid be made visible? — Can you explain the structure and use of the Galvanic battery? — How is it made to operate? — Explain the use of the glasses represented by fig. 2. — Can the Galvanic shock be made to pass through several persons, and by what means? — In what way are metallic wires fused by Galvanism? How is gunpowder inflamed by it? — Can other substances be melted? — Under what circumstances does the Galvanic battery act the best?

CONVERSATION III.

GALVANIC CONDUCTORS—CIRCLES—TABLES—EXPERIMENTS.

Father. You know that *conductors* of the electric fluid differ from each other in their conducting power.

Ch. Yes: the metals are the most perfect conductors; then charcoal; afterwards water and other fluids.

Fa. In Galvanism we call the former *dry* and *perfect* conductors; these are the first class: the latter, or second class, *imperfect* conductors: and in rendering the Galvanic power sensible, the combination must consist of three conductors of the different classes.

Ja. Do you mean two of the first class, and one of the second?

Fa. When two of these bodies are of the first class, and one is of the second, the combination is said to be of the *first order*.

Ch. The large battery, therefore, which you used yesterday was of the *first order;* because there were two metals—viz., zinc and silver, and one fluid.

Fa. This is called a *simple Galvanic circle:* the two metals touched each other in some points; and at other points they were connected by the fluid, which was of the different class.

Ja. Will you give us an example of the second order?

Fa. When a person drinks porter from a pewter vessel, the moisture of his under lip is one conductor of the second class; the porter is the other; and the metal is the third body, or conductor of the first class.

Ch. Which are the most powerful Galvanic circles?

Fa. They are those of the first order, where two solids of

different degrees of oxidability are combined with a fluid capable of oxidating at least one of the solids. Thus gold, silver, and water, do not form an active Galvanic circle, but it will become active if a little nitric acid, or any fluid decomposible by silver, be mixed with the water. An active Galvanic circle is formed of zinc, silver, and water, because the zinc is oxidated by water. But a little nitric acid, added to the water, renders the combination still more active, as the acid acts upon the silver and the zinc.

The most powerful Galvanic combinations of the second order are, where two conductors of the second class have different chemical actions on the conductors of the first class, at the same time that they act upon each other. Thus, copper, silver, or lead, with a solution of an alkaline sulphuret and diluted nitric acid, form a very active Galvanic circle.

I will now show you another experiment, which is to be made with the assistance of the great battery.

Fig. 4.

A B exhibits a glass tube filled with distilled water, and having a cork at each end. A and B are two pieces of brass wire, which are brought to within an inch or two of one another in the tube, and the other ends are carried to the battery—viz., A to what is called the positive end, and B to the negative end.

Ja. You have, then, positive and negative Galvanism, as well as electricity?

Fa. Yes; and if the circuit be interrupted, the process will not go on. But if all things be as I have just described, you will see a constant stream of bubbles of gas proceed from the wire B, which will ascend to the upper part of the tube. This gas is found to be hydrogen or inflammable air.

Ch. How is that ascertained?

Fa. By bringing a candle close to the opening, when I take out the cork A, the gas will immediately ignite. The bubbles which proceed from the wire A are oxygen: they accumulate and stick about the sides of the tube.

Ja. How is this experiment explained?

Fa. The water is decomposed into hydrogen and oxygen: the hydrogen is separated from the water by the wire connected with the negative extremity, while the oxygen unites with and oxidates the wire connected with the positive end of the battery.

If I connect the positive end of the battery with the lower wire, and the negative with the upper, then the hydrogen proceeds from the upper wire, and the lower wire is oxidated.

If wires of gold or platina be used, which are not oxidizable, then a stream of gas issues from each, which may be collected, and will be found to be a mixture of hydrogen and oxygen.

Ch. Are there no means of collecting these fluids separately?

Fa. Yes: instead of making use of the tube, let the extremities of the wires which proceed from the battery be immersed in water, at the distance of an inch from each other: then suspend over each a glass vessel, inverted and full of water, and the different kinds of gas will be found in the two glasses.

Fig. 5

It is known that hydrogen gas reduces the oxides of metals; that is, restores them to their metallic state. If, therefore, the tube (fig. 4) be filled with a solution of acetate of lead* in distilled water, and a communication is made with the battery, no gas is *perceived* to issue from the wire, which proceeds from the *negative* end of the battery; but in a few minutes beautiful metallic needles may be seen on the extremity of the wire.

Ja. Is this the lead separated from the fluid?

Fa. It is: and you perceive it in a perfect metallic state, and very brilliant. Let the operation proceed, and these needles will assume the form of a fern, or some other vegetable.

Ch. Can other metals be separated in this way?

Fa. They can, and a knowledge of this fact has become of vast importance in the arts. For by attaching objects of any kind which are conductors of electricity to the negative wire, they will become coated with the metal. In this manner most of our forks, spoons, and various other articles, are plated, or coated with a thin layer of silver or gold. Medals, seals, plaster of Paris casts, and various other articles, may be copied by this process, which is called *Electrotype* or *Electroplating*. The object to be coated, is first cleaned, then placed in a vessel containing a solution of sulphate of copper, being supported in it upon a flat fold of the wire coming from the negative plate of such a battery as that figured at page 548. All those parts which are not to be coated, must be covered with wax, varnish, or some other non-conducting substance. The wire connected with

the positive pole is attached to a plate of copper or a piece of platinum foil, which is also immersed in the solution of copper. When the coating of copper thrown down upon the medal has acquired sufficient thickness, it may be separated from the medal, and will be found to present an exact copy of it, even the most delicate lines being perfectly distinct.

If the objects are to be coated with silver or gold, a solution of these metals must of course be substituted for the copper.

Ch. But supposing I wished to copy a plaster of Paris cast, or a seal, how should I then proceed?

Fa. Simply by rubbing the object with powdered black lead; this will render it a conductor of electricity.

QUESTIONS FOR EXAMINATION.

Into what classes are conductors of Galvanism divided?—To make a complete combination, how many conductors must there be?—When is the Galvanic combination said to be of the first order? — What is meant by a simple Galvanic circle?—Illustrate by an example what is meant by a combination of the second order.—Which are the most powerful Galvanic circles?—Describe the experiment exhibited by fig. 4.—How is it accounted for?—What circumstance occurs if wires not oxidizable are used?—How are the two gases obtained separately? — What effect has hydrogen gas on the oxides of metals?—What experiment is there in proof of this?—What is meant by electrotype? — How is electroplating accomplished?

* Acetate of lead is a solution of oxide of lead in acetic acid.

CONVERSATION IV.

MISCELLANEOUS EXPERIMENTS.

Father. The discoveries of Galvani were made principally with dead frogs. From his experiments, and many others that have been made since his time, it appears that the *nerves of animals* may be affected by very small quantities of electricity. Hence limbs of animals, properly prepared, have been sometimes employed for detecting currents of Galvanic electricity.

Ch. What is the method of preparation?

Fa. I have been cautious in mentioning experiments on animals, lest they should lead you to trifle with their sufferings.

The muscles of a frog lately dead, and skinned, may be brought into action by means of very small quantities of common electricity.

If the leg of a frog recently dead be *prepared*, (that is, separated from the rest of the body,) having a small portion of the spine attached to it, and so situated that a little electricity may pass through it, the leg will be instantly affected with a kind of spasmodic contraction, sometimes so strong as to cause it to leap to a considerable distance.

Similar effects may be produced in the limb thus prepared, by only making a communication between the nerves and the muscles by a conducting substance. Thus, in an animal recently dead, if a nerve be detached from the surrounding parts; and the muscles exposed which depend on that nerve; and a piece of metal wire touch the nerve with one extremity, and the muscle with the other, the limb will be convulsed.

Ch. Is it necessary that the communication between the nerve and the muscle should be made with a conducting substance?

Fa. Yes: for if sealing-wax, or glass, &c., be used instead of metals, no motion will be produced.

If part of the nerve of a *prepared* limb be wrapped up in a slip of tin-foil, or be laid on a piece of zinc, and a piece of silver be laid with one end upon the muscle, and the other on the tin or zinc, the motion of the limb will be very violent.

Here are two wine-glasses almost full of water; and so near to each other as barely not to touch: I will put the *prepared* limb of the frog into one glass, and lay the nerve, which is wrapped up in tin-foil, over the edges of the two glasses, so that the tin may touch the water of the glass in which the limb is not. If I now form a metallic communication between the water in the two glasses, as by a pair of sugar tongs, or put the fingers of one hand into the water of the glass that contains the leg, and hold a piece of silver in the other, so as to touch the coating of the nerves with it, the limb will be immediately excited: and sometimes, when the experiment is well made, the leg will even jump out of the glass.

Ja. It is very surprising that such motions should be produced in dead animals.

Fa. They may be excited also in living ones. If a live

frog be placed on a plate of zinc, having a slip of tin-foil upon its back, and a communication be made between the zinc and tin-foil, by a piece of metal, the same kind of contractions will take place.

Ch. Can this experiment be made without injury to the animal?

Fa. Yes: and so may the following:—Take a live flounder and dry it with a cloth, and then put it in a pewter plate, or upon a large piece of tin-foil, and place a piece of silver on its back: now make a communication between the metals with any conducting substance, and you will soon see the contractions and the contortions of the fish.

Place this leech on a crown piece, and then, in its endeavour to move away, let it touch a piece of zinc with its mouth, and you will see it instantly recoil, as if in great pain: the same thing may be done with a worm.

It is believed that all animals, whether small or great, may be affected, in some such manner, by Galvanism, though in different degrees.

By the knowledge already obtained in this science, the following effects are readily explained.

Pure mercury retains its metallic splendour during a long time; but its amalgam is soon tarnished or oxidated.

Ancient inscriptions, engraved upon pure lead, are preserved to this day; whereas some medals composed of lead and tin of no great antiquity, are very much corroded.

Works of metal, the parts of which are soldered together by other metals, soon oxidize about the parts where the different metals are joined; and there are persons who profess to find out seams in brass and copper vessels by the tongue, which the eye cannot discover; and who can, by this method, distinguish the base mixtures which abound in gold and silver trinkets.

When the copper sheathing of ships is fastened on by means of iron nails, those nails, and particularly the copper itself, are very quickly corroded about the place of contact.

A piece of zinc may be kept in water a long time, without scarcely oxidating at all; but the oxidation takes place very soon if a piece of silver touch the zinc while remaining in the water.

If a cup made of zinc or tin be filled with water, and placed

upon a silver waiter, and the tip of the tongue be applied to the water, it is found to be insipid; but if the waiter be held in the hand, which is well moistened with water, and the tongue applied as before, an acid taste will be perceived.

Ch. Is that owing to the circuit being made complete by the wet hand?

Fa. It is. Another experiment of a similar kind is the following:—If a tin basin be filled with soap-suds, lime-water, or a strong ley, and then the basin be held in both hands, moistened with pure water, while the tongue is applied to the fluid in the basin, an *acid* taste will be sensibly perceived, though the liquor is *alkaline.*

From this short account of Galvanism it may be inferred:—

1. That it appears to be only another mode of exciting electricity.
2. Galvanic electricity is produced by the chemical action of bodies upon each other.
3. The oxidation of metals appears to produce it in great quantities.
4. Galvanic electricity can be made to set inflammable substances on fire, to oxidize and even inflame metals.
5. The nerves of animals are easily affected by it.
6. Galvanic electricity is conducted by the same substances as common electricity.
7. When it is made to pass through an animal, it produces a sensation resembling the electrical shock.

It must also be recollected that electricities, from whatever source derived, are identical. They differ merely in what is called their tension and quantity. You may readily understand what is meant by their tension; for if I charge a small Leyden jar with a certain amount of electricity, and then charge one twice as large with the same amount, on discharging each, the spark will be very much greater in the former than in the latter, on account of its being distributed over a much smaller surface. In galvanic electricity we have great quantity, but little tension; in frictional electricity we have great tension, but little quantity.

QUESTIONS FOR EXAMINATION.

What parts of the animal are most affected by the electric fluid?—How are the limbs of animals affected by it?—Are conducting substances necessary for these experiments?—Tell me the method of making an experiment

of this kind.—How may living animals, as a frog, or a flounder, be excited by Galvanic experiments?—Why is amalgam soon oxidated?—Will Galvanism account for the preservation of ancient inscriptions upon pure metals, while those on mixed metals are quickly corroded?—How have some persons pretended to find out the seams in brass and copper vessels?—Why is the copper sheathing on ships so soon corroded?—Under what circumstances is zinc quickly oxidized?—What experiment is made with a cup composed of tin and zinc?—What is that made with soap-suds?—What is Galvanism?—How is the Galvanic electricity produced?—What yields this fluid in great quantities?—What powerful effects does it produce?—What parts of animals are chiefly affected by Galvanism?—By what substances is this fluid conducted?—How does it affect the animal frame?

ELECTRO-MAGNETISM.

Ch. Will you tell me, papa, something about electro-magnetism?

Fa. With pleasure; the subject is a most interesting one, and has found most extensive and important application. You will appreciate this remark when I tell you that upon the principles of electro-magnetism is based the wonderful Electric Telegraph; it may also be applied to clocks, and would undoubtedly come into competition with steam, as an agent for setting machinery in motion, if the production of the electric current did not involve such expense. I will first show you how to magnetise a body by an electric current. If you wind a length of copper wire several times around a pencil or a rod of any kind, thus making a coil such as you have seen attached to the bell in the kitchen, next place a needle or piece of steel inside the coil, and then pass a current of electricity either from the electric machine or a galvanic battery through the coiled wire, you will convert the needle or the piece of steel into a magnet.

Ch. Will the needle, when taken out of the coil, affect the compass, or point to the north?

Fa. It will, if it consist of steel, but not if composed of soft iron; for the latter will not retain magnetism, as you know, whilst steel will do so.

Ch. Can you affect a compass needle by a current of electricity passed through a wire, without the presence of another needle capable of being magnetised?

Fa. You can. If you hold a compass needle above or

beneath, but parallel to, a straight horizontal wire forming one of the poles of a battery, you will find the needle is moved out of its course. But you will see this better by winding some copper wire into a flat coil, and arranging this as shown in the figure. Upon delicately balancing a magnetised needle within the coil, giving the coil a polar direction, and then passing an electric current through the latter, the needle will be still more turned from its natural position, or deflected, as it is called. This most interesting experiment was first made by Professor Oersted, of Copenhagen, and forms the principle of electro-magnetism.

Ch. Does not the electricity run through the portions of the copper wire which are in contact?

Fa. They do, and it is an important point to take care that the wire be spun round or covered with cotton, otherwise the electricity will not pass through the whole length of the wire.

Ch. Can I make a large magnet in this way?

Fa. You can. If a large bar of soft iron be bent into the shape of a horseshoe, and some of the covered wire be wound many times around it, upon passing a current of galvanic electricity through the wire, the horse-shoe will become an immensely powerful magnet; if the battery be at all strong, it may be made to support some hundred-weights, nay, even tons. The horse-shoe, however, loses its magnetism directly the current is broken, and the weight previously supported falls off.

Ch. I do not find that the coil of copper wire has retained its magnetism.

Fa. Certainly not: but a delicate coil, such as that in which we first placed the needle, will itself take the direction of a magnet if carefully poised, so as to be able to move freely, but this only so long as it is traversed by the current; and if two coils of this kind be approximated, they will attract and repel each other like common magnets.

Ch. But how is the magnetism, in these cases, produced by the electricity?

Fa. It arises from what has been called induction. You have seen that an electric current is, in certain cases, accompanied with magnetic currents; but the fact is applicable to electric currents in general—wherever an electric current

exists, there are magnetic currents also. The close connexion between electricity and magnetism has long been known: thus, that the magnetism of a compass-needle in a ship has been deranged or disturbed by a flash of lightning or during a storm, has been pointed out many years ago; and the most plausible explanation that has yet been given of these phenomena is, that every particle of a magnet is surrounded by an electric current in a constant state of circulation, whilst in unmagnetized iron the electricity exists also, but in a quiescent state. Upon approximating a piece of iron or steel to a magnet, or exposing it to the action of a current of electricity, the electric equilibrium is disturbed, the above minute currents are set in motion, or induced, and thus exhibit visible effects. You recollect that the magnetic force acts in a direction at right angles to the current in the conducting wire; I must also tell you, that in accordance with the above view, the directions of the currents surrounding the two poles of a magnet are different.

Ch. But can electric currents be caused by magnetism?

Fa. They can. If a bar magnet be inserted in a coil of covered wire, such as we have alluded to, a current of electricity will be set in motion, and on withdrawing the magnet another current will move in the opposite direction. This is called magneto-electricity; and by somewhat varying the form of the apparatus, by making larger coils rotate rapidly near the poles of a large magnet, powerful currents of electricity, capable of exhibiting all the ordinary effects, may be produced. The next time we go to the Polytechnic Institution I will show you Clark's magneto-electric machine, which is a very powerful instrument of this kind.

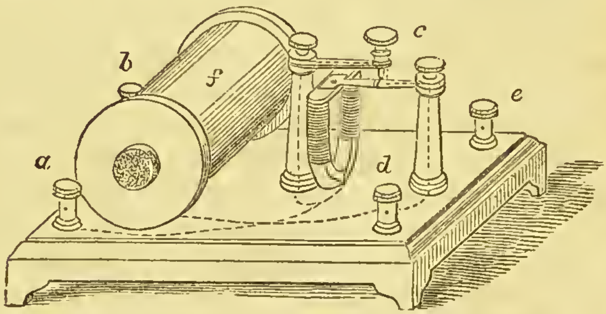
Ch. But I have had a very strong shock from an apparatus consisting of two coils of wire.

Fa. I have no doubt. Secondary or induced currents may be set in motion in another way. When a current of electricity traverses a wire, if another wire be placed parallel with this, a new current will be set up taking an opposite direction to the former, and as soon as the primary or first current in the first wire is interrupted, by breaking the contact with the battery, the direction of a secondary current in the wire is reversed. These secondary or induced currents, which are very powerful if large coils of wire be used,

will give a strong shock even when the battery is not strong. But you must recollect that induced currents may be set up, even if the wire through which the primary current itself passes be coiled, because here again we have the wires or rather the coiled portions running parallel—the requisite condition for the production of secondary currents.

Ch. I recollect when I had my shock that it was much stronger when the bar of iron was inserted.

Fa. Certainly. The bar is itself, as I have already shown you, capable of exciting currents, which, in addition to those existing without it, must augment the intensity of the secondary currents. By these currents all the ordinary effects of electricity may be produced, sparks, the decomposition of water, &c., and as this is the kind of electricity generally used now for medical purposes, I shall show you how the apparatus is arranged. It also illustrates very beautifully several points to which I have alluded. *f* represents a wooden



reel, upon which two coils of wire are wound. The first coil, which is called the primary coil, takes rather a circuitous course, but which is essential to be clearly understood. It commences at the binding-screw *b*, is wound around the reel, and, leaving this, follows the course of the dotted line beneath the stand to reach the right-hand column, to the bottom of which it is soldered. Another portion of the same wire is soldered to the bottom of the other column next the reel; it then passes to the horse-shoe, is wound around this, and leaving it, passes directly to the binding-screw *a*. The other, or secondary coil, is composed of much thinner wire, and is considerably longer. Its ends pass directly from the reel to the binding-screws *d*, *e*. There is a keeper to the horse-shoe, connected

to the column by a flat piece of steel, and the point of the screw *c*, rests upon this. Now when the poles of the battery are connected with the two ends of the primary coil, by insertion in the binding-screws *a*, *b*, the current of electricity follows the course of the dotted line, and on passing through the coil surrounding the horse-shoe, it converts this into a temporary magnet, which consequently attracts the keeper, and withdraws it from contact with the point of the screw *c*. Thus the course of the current is interrupted, whereby the horse-shoe loses its magnetism, and ceasing to attract the keeper, this is carried back by the steel spring, until the latter again comes into contact with *c*, when the current is again transmitted. Each time the passage of the primary current is interrupted, a secondary current is transmitted through the secondary coil; and if two wires with handles be inserted in the binding-screws *d*, *e*, a shock is experienced every time the connexion is broken. The centre of the reel is hollow, and contains a bundle of iron wires, by the removal or insertion of which, the strength of the shock may be diminished or increased at pleasure.

Ch. Can the magnetism of the earth be accounted for by electricity?

Fa. You have anticipated me in this very sensible question. For the most plausible explanation that can be given of the magnetism of our earth consists in attributing it to this cause; and we have sufficient evidence of the existence of electric currents circulating around the earth, to account for it. You know that the sun, in its diurnal motion, follows the ecliptic, which does not coincide with the equator, as we have already seen. Now it will not appear to you improbable that the sun in its course, by unequally heating the earth's surface, will disturb the electric equilibrium, and various electric currents will be produced mainly in the direction of the ecliptic. Hence we see that the magnetic equilibrium must also be disturbed, and magnetic currents be also set in motion, the magnetic force acting at right angles to the electric currents.

Ch. Could I then make a globe showing the manner in which the magnetism of the earth is produced?

Fa. You can. By coiling covered copper wire around a wooden sphere, and connecting the ends of the coil with the

poles of a battery, on applying a delicately supported little magnet to various parts of the sphere, the variations of the needle and its dip will be found to coincide with those occurring upon the earth.

QUESTIONS FOR EXAMINATION.

How may a body be magnetized by electricity?—What is the difference between a piece of steel and of soft iron when thus magnetized?—Show me that a magnetic needle can be deflected by the poles of a battery, and explain the meaning of deflection?—What is the use of covering conducting wires with cotton?—How would you convert a large bar of soft iron into a temporary magnet?—How can a coil of copper wire be made to assume a polar direction?—What is the meaning of induction?—How can electric currents be caused by magnetism?—What is magneto-electricity?—What is meant by a secondary coil; also, a secondary current?—Explain the action of the apparatus figured at page 560?—How can the magnetism of the earth be explained?—How would you construct a globe representing the earth, and capable of exhibiting its magnetism and polarity?

ON DIAMAGNETISM.

Fa. I shall now say a few words to you in regard to diamagnetism; a new magnetic property of bodies which was discovered by Dr. Faraday in 1845.

Ch. How does diamagnetism differ from magnetism?

Fa. You recollect my showing you how an electro-magnet, like a common load-stone or magnet, attracted magnetic bodies; just the opposite occurs when diamagnetic substances are presented to an electro-magnet, for they are all repelled by it, and it appears that almost all bodies are either magnetic or diamagnetic.

Ch. Will you mention some diamagnetic substances, papa?

Fa. Bismuth, antimony, tin, phosphorus, and flint glass, are strong bodies of this class; whilst water, ether, and spirit, possess the property to a less degree; and it has been found, that by mixing magnetic with diamagnetic bodies, their distinctive properties may be neutralized.

As this most interesting subject is still undergoing investigation, I shall postpone, for the present, attempting to give you any explanation of the phenomena.

QUESTIONS FOR EXAMINATION.

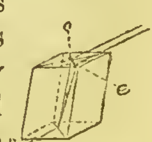
How does diamagnetism differ from magnetism?—Mention some diamagnetic substances?

ON THE DOUBLE REFRACTION AND POLARIZATION OF LIGHT.

Fa. In Conversation III., we considered the ordinary refraction of light, and the laws to which it is subject. But in passing through many bodies, light suffers a further change than that merely of direction, being split or separated into two equal rays, or doubly refracted, as it is called.

Ch. How can we see this?

Fa. It is most readily seen in a crystal of calcareous spar. This beautiful mineral crystallizes in obtuse rhomboids; and if we take one of them, and look through it at a piece of black paper with a hole in it, we shall see two holes instead of one; or if the crystal be placed over some print, two sets of letters will be seen, instead of the single set seen when print is looked at through glass. Thus, the pencil of rays of light admitted through the hole in the paper is resolved into two other pencils, one of which follows the ordinary course, and is called the ordinary ray; the other takes a different course, and is called the extraordinary ray. This is represented in the



figure, in which *r* represents the light as it is entering the crystal, *o* the ordinary, and *e* the extraordinary ray.

Ch. Is this effect produced in whatever direction we look through the crystal?

Fa. No. In all doubly-refracting bodies, there are one or more directions in which there is no double refraction. Crystals in which only one such direction exists are said to have one axis of double refraction; those in which two exist, two axes, and so on.

Ch. Is the light altered in any way by this curious double refraction?

Fa. It is; and the two rays possess very remarkable properties. Thus, if they be viewed through a second crystal of calcareous spar, placed in exactly the same manner as the first, but above it, they will both be distinct; but on turning the second crystal round between the finger and thumb, the two rays which were at first visible will gradually disappear,

and two others will come into view. On continuing the rotation of the second crystal, the two last produced will also disappear, and the two first be again seen. This disappearance and reappearance is found to take place at each quarter of a revolution of the second crystal.

Ch. What is light thus altered called?

Fa. It is said to be *polarized;* having, as it were, acquired sides, the opposite properties of the different sides being supposed to bear some analogy to the opposite properties of the different poles of a magnet. According to the undulatory theory, the particles of polarized light are supposed to undulate in one plane; whilst, in common light, the planes of undulation are in all directions.

Ch. Can light be polarized by any other means than passing through calcareous spar?

Fa. Yes; by reflection from the surface of bodies at the proper angle, which varies according to the nature of the bodies; also by refraction through plates of glass. Some bodies doubly refract and polarize light, but absorb one set of the rays. A very useful body of this kind is the mineral called tourmaline; and thin slices of this, cut parallel to the axis or length of the crystal, are very frequently used for polarizing light.

Ch. How does the hole in the paper appear through a plate of tourmaline?

Fa. We see only one image of it; and on turning round the plate in the same manner as we did the second crystal of calcareous spar, one of the images vanishes at each quarter of a revolution.

Ch. And how do substances produce this polarization of the rays of light?

Fa. The intimate nature of the process is unknown, but it may be represented by supposing—as in the tourmaline, for instance—the existence of a structure which would act like a grating, as at *b*, fig. 3. When the plane in which the undulations move is parallel to the direction of the bars of the grating, the rays will pass; but when it is not, they will be obstructed in their passage. Now, supposing the dots to represent the particles of light moving in the plane *c:* on presenting these to the tourmaline, the rays will pass through it; but on

Fig. 1.

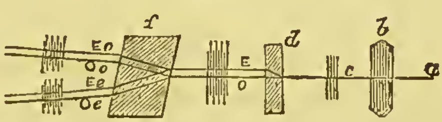
rotating the tourmaline, they will be obstructed. Now, in doubly refracted light both the rays are polarized, but the undulations are in planes at right angles to each other as in fig. 2, so that one set only will pass through the crystal at each quarter of a revolution.

Fig. 2.

Ch. I have heard of colours being produced by polarized light: how is this done?

Fa. Colours are seen when doubly-refracting crystals or substances are placed between the two crystals of calcareous spar, or two plates of tourmaline; and these colours are of the most beautiful and vivid kind; but the manner in which they are produced is difficult to be understood, and will require your greatest attention. In all experiments with polarized light, the first doubly-refracting or polarizing crystal—that placed beneath the body to produce the colour—is called the polarizer, because it polarizes the light; whilst the other crystal or plate of tourmaline is called the analyzer, because it analyzes or tests the light as polarized by the first. Now let us take a tourmaline, a thin plate of selenite, or any other doubly-refracting crystalline substance, and a crystal of calcareous spar as an analyzer. On holding these to the light, the plate of selenite presents the most gorgeous colours, which vary with each quarter revolution of the analyzer, the colours seen during one quarter of a revolution being complementary to those of the next; and I must tell you, that by complementary colours is signified such as are required to be mixed with any other colour to convert such colour into white; thus, red is complementary to green, yellow to deep violet-blue, &c. The accompanying diagram exhibits the

Fig. 3.



various crystals, and gives a notion of the changes undergone by the light. *a* represents a ray of light entering *b*, the polarizer, by which it is polarized, or all those undulations in it which are not in one plane obstructed; it passes on to *d*, the plate of selenite, which doubly refracts this polarized light—*i. e.*, it resolves it into two sets of rays, the ordinary

and extraordinary, O and E, polarized in planes at right angles to each other. Now the extraordinary rays take a longer course in the plate than the ordinary; and on their emergence, the undulations do not coincide, or are not in the same state of vibration, one set being half an undulation behind the other. On entering the analyzer, *f*, each of these sets is again resolved into two others, making four in all, which are in two planes—*i. e.*, two in one plane, and two in another; and as the vibrations or undulations in the same plane do not coincide, one set having been retarded, the undulations interfere and produce colour, as we explained in a former conversation. If the analyzer be, as we have supposed, a crystal of calcareous spar, both sets of colours which are complementary to each other will be seen at the same time, and will vary as the analyzer is rotated; whilst, if the analyzer consist of a tourmaline, the complementary tints will be seen singly and alternately as the rotation is made. The colours produced will vary according to the thickness of the plate, but they must always be complementary.

If a section of any doubly-refracting crystal, made at right angles to its refractive axis or axes, be substituted for the plate of selenite, a black cross and one or more sets of coloured rings will be seen, presenting a most beautiful appearance, the black cross arising from the light not being doubly refracted at this part; and as the analyzer is rotated, the cross will become white for the same reason.

The phenomena presented by the action of polarized light upon bodies are of the most interesting kind; the beauty and variety of the tints, the regularity of their arrangement around the axes of crystals, and the changes they undergo, are such as to render this the most interesting branch of optics.

QUESTIONS FOR EXAMINATION.

What is meant by double refraction?—How may this be shown?—What is meant by an axis of double refraction?—What is meant by polarized light?—How can you show that light is polarized?—What is the difference as regards the planes of undulation, between common and polarized light?—What other methods are there of polarizing light, besides double refraction?—Give me an idea of the action of the tourmaline upon polarized light?—How are colours produced by polarized light?—What is meant by a polarizer, and an analyzer?—What is meant by complementary colour?—Explain the difference between an ordinary and extraordinary ray?

ADDITIONAL CONVERSATION.

RECENT DISCOVERIES.

Fa. Before we part this evening, I propose to notice a few subjects which are either comparatively new, or have become important from their novel application to the arts of life. I may first enumerate them: they are, the Rotation of the Earth as shown by the pendulum, the Screw-propeller, the Electric Telegraph, the Aneroid Barometer, and the Stereoscope.

Ch. I shall be delighted to hear your explanations, father; for I have heard a great deal about the screw-propeller, and the electric telegraph, and have seen the stereoscope, but have failed to understand the principles upon which they act.

Fa. Well, we will consider them in order, and begin with the Rotation of the Earth.

Ch. I recollect your telling us that the earth performed two motions of rotation, one upon its axis, and called the diurnal motion or rotation; the other around the sun, called its annual motion, and giving rise to the seasons.

Fa. True; but the rotation I now wish to speak of is the former, or the diurnal rotation of the earth upon its axis, producing day and night. You will remember that the evidence of this rested principally upon the apparent motion of the sun and stars. But a novel experiment has been devised by M. Foucault, a French philosopher, showing this rotation by means of a pendulum. This consists of a metallic ball suspended from the ceiling of a high room; and the success of the experiment depends upon the fact that on moving the point of suspension of a vibrating pendulum, the direction of its motion is not interfered with. When the pendulum is made to vibrate in the meridian, if a line be drawn upon the floor so as to coincide with this direction, in a short time the direction of the vibrating pendulum will be found not to coincide as it did at first with the line, but to form an angle with it. The reason of this is, that during the con-

tinuance of the vibration of the pendulum, the earth has rotated beneath it, carrying with it the line, and so as it were, left the pendulum behind.

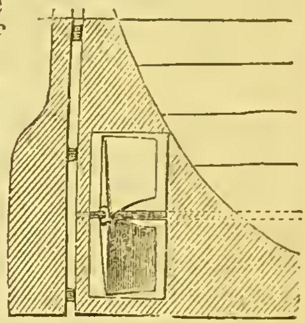
Ch. This is, indeed, a very ingenious and conclusive experiment.

Will you next tell us about the Screw-propeller, of which we have heard so much lately. Are not the war-ships now provided with this contrivance?

Fa. They are so, and perhaps one of the most important uses of the screw is for war-ships, because it is not exposed to the shot of the enemy.

Ch. Where is the screw placed? I saw a screw-steamer in the Thames one day, but I could not perceive the means by which it was moved, for there were no paddle-wheels.

Fa. The screw is situated in a quadrangular opening between the lower and fore part of the rudder and the lower and back part of the keel, so that it is invisible when the ship is in the water. It lies horizontally, or nearly so, and parallel with the keel of the ship. The form of screw used is not always the same. The simplest is that of an ordinary screw, with a very broad thread. This form, however, is not often used now; but one in which the broad thread is cut away, excepting two or sometimes three radial portions, as they might be called; and the correspondence of these portions, which are called blades, with parts of a screw might be easily overlooked.



Ch. But how does the screw act, and by what is it moved?

Fa. The source of motion is a steam-engine, which rotates with rapidity the axis or cylinder of the screw; the tendency of this rotation is to drive the water backwards, and in consequence of the corresponding reaction, to urge forwards the screw and the vessel, which may be considered as one. When the screw revolves in the opposite direction, so as to tend to drive the water forwards, the boat will be urged backwards.

Ch. The third subject on your list is the Electric Tele-

graph. I recollect your telling me that the principles upon which the electric telegraph was based were those of electro-magnetism, but I cannot comprehend how words can be conveyed by electro-magnetism, or by wires.

Fa. I dare say not; but I think this difficulty may soon be got over. It need scarcely be told you that the wires merely convey an electric current, and not sounds. The words are conveyed by signs mutually agreed upon before-hand by the persons stationed at each end of the wires; and these signs consist of deflexions of a magnetic needle produced by the electric current.

Ch. I begin now to have some idea of the manner in which the communication might take place. For it is evident that if each letter of the alphabet were signified by a certain number of deflections of the needle, there would be no difficulty in the matter.

Fa. You are quite correct; and the plan you have suggested is that usually adopted. But the process has been much simplified and abbreviated by attention to certain circumstances. Thus, the deflection of a magnetic needle varies according to the direction in which the current of electricity passes through the coil of wire, and by changing this direction, the needle may be deflected to the right or the left at will. Hence, two distinct signs may be made with a single needle. Again, by using a number of needles and wires, which can be worked simultaneously, the communication is still further simplified.

Ch. Are there then half as many needles in use as there are connecting wires?

Fa. No; the returning electric current is conveyed by the earth, which has been found to answer the purpose sufficiently well, so that each of the wires which you see on the side of a railway belongs to a single needle.

Ch. But how are the currents conveyed across the sea?

Fa. By wires, as on the land. The great difficulty to be overcome consisted in insulating the wires when immersed in so good a conductor as water. This has been effected by enclosing them in tubes made of gutta percha, which is a very bad conductor of electricity, and possesses the valuable property of being easily moulded or its surfaces united by means of heat. Long tubes of this substance enclosing the

wires are laid upon the bottom of the sea, and extend from one telegraph-station to the next.

Ch. Then I suppose that the pieces of glass and earthenware by which the wires are supported upon the poles at the side of the railway-lines also act as insulators.

Fa. Exactly so; if these were absent, when the poles became wet, the electric current would descend the poles, and return by the earth, and so the communication with the distant station would be interrupted.

Ch. But it must be very fatiguing for any one to sit and watch constantly whether the needle or index hand of the telegraph moves or not.

Fa. This would certainly form a difficulty; for whilst the attention of the telegraph-worker were withdrawn for even a short period, several of the signals, denoting letters and words, might have been made and not seen. This is obviated by the attention being drawn when the signals are about to be made by the ringing of a little bell, which is instantly heard by an attendant.

Ch. But how is this effected?

Fa. By means of an electro-magnet. I told you in a former Conversation, that a piece of soft iron surrounded by a coil of wire through which a current of electricity is passed, becomes temporarily magnetic; hence, if the piece of iron were in the form of a common horse-shoe magnet, for instance, and the keeper were connected with a little bell, either by means of a lever or in some other way, as soon as the current was transmitted through the wire the magnet would attract the keeper and set the bell in motion. As soon as the worker of the telegraph has heard the bell, and is ready to attend to the signals, he rings by the same means at the distant station to signify that this is the case. Various modifications of the electric telegraph are in use at different places, to enter into which, we have not at present time; but I hope enough has been said to render intelligible to you the general principles upon which they are based.

Ch. Will you now explain to me the manner in which the Stereoscope produces such remarkably deceptive appearances, for they seem to me very puzzling?

Fa. Certainly; and in so doing I must recal to your mind what I said in a former Conversation regarding the

manner in which the interpretations of the impressions made upon the eye are controlled by experience; and when this experience has not been obtained, the simple sense of sight is very deceptive as to the form and distance of objects. So much so, that in certain instances which have occurred of persons born blind, and whose sight has been subsequently restored when their reason has become matured, the most erroneous ideas have been entertained as to the form and distance of objects; thus, the latter, although distant, have appeared to be close to the eye, and it was found impossible to decide whether the sense of touch or of sight was to be trusted in determining the form of objects. And in certain engravings in which the shadows which would have been formed by the figures were very exactly represented, the idea has been conveyed to the mind that these figures were really solid; a fallacy only to be detected by the sense of touch.

In the stereoscope which we are considering, the fallacy is connected with the judgment formed from the perspective view of objects. When we look at any solid body with each eye separately, *i.e.*, closing one with the finger, then closing the other while the first eye remains open, two distinct perspective views of the object are obtained. Thus in the instance of the cube represented below, Fig. 1 would repre-

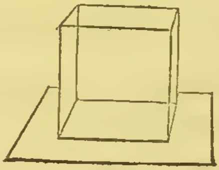


Fig. 1.

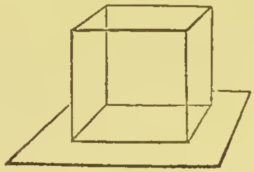


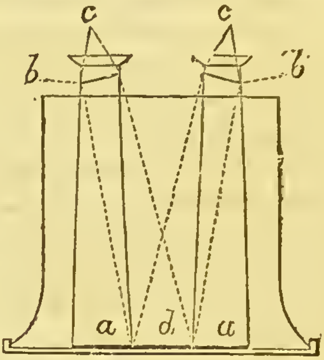
Fig. 2.

sent the view as seen with the left eye only open, and Fig. 2, that with the right eye open. Now under ordinary circumstances, these two images of the cube being seen simultaneously, and depicted upon corresponding parts of the retinæ of the two eyes, the idea conveyed to the mind is that of a single object; and as previous experience has taught us that all single objects which present two perspective views are solid, we naturally conclude that the cube is solid, even without taking it into our hands.

It is evident, however, that the two drawings of the cube do not appear to the eye as a solid body, although they

clearly present the proper perspective views; and this because the two perspective views do not appear to emanate from one object, the rays from each figure impinging upon different parts of each retina, as if from two different objects or bodies.

But when the drawings are viewed through the stereoscope, the rays, *a*, proceeding from each drawing are refracted outwards, at the same angle as each set of rays would have formed had they proceeded from a single object, *d*, placed in the centre of the box. Hence we obtain the requisite conditions for the production of the impression upon the mind of the existence of a single solid object, *i.e.*, two perspective views apparently emanating from one object, and impinging upon corresponding parts of the retinæ of the two eyes.



Ch. But how is this refraction outwards produced?

Fa. By two slightly magnifying lenses, inclined outwards, and situated one in each eye-piece at *b b*.

Ch. Then if I were to turn round either of the eye-pieces, I should lose the solid appearance of the figures?

Fa. Certainly; and you would see two distinct plane or flat figures, for the reason stated above.

Ch. The stereoscope then shows a use of our having two eyes instead of one which never occurred to me; and I suppose that a man who had lost the sight of one eye would be unable to distinguish whether an object were solid or not?

Fa. To such a man, solid objects would doubtless not appear to be so, but by changing the position of his head he would easily obtain two perspective views, and so might conclude as to the solidity of a body.

Ch. Would it be possible to reflect the images of two plane figures in such manner as to make them represent a single solid body?

Fa. Certainly; I omitted to tell you that the stereoscope mentioned above, containing the lenses, is called the Lenticular, or Refracting Stereoscope; but the first one made was

upon the reflecting principle, and is called the Reflecting Stereoscope.

Fa. The Aneroid Barometer was invented by M. Vidi, of Paris; and although it is not so perfect a philosophical instrument as the mercurial barometer, yet it possesses the great advantage of extreme portability, for it is not more than about five inches in diameter, and two in thickness. In form it resembles a watch of the above dimensions. Upon its face is a curved graduated scale, the degrees of which correspond to the altitude in inches and fractional parts of the mercurial barometer; a thermometer is also affixed to the face, and the indications are made by an arrow-shaped hand.

Ch. I think then I have seen the aneroid barometer in a shop-window, with the case made of brass.

Fa. Very probably, for they are everywhere to be seen in London. Inside the case is a circular flat metallic box, of about two-thirds the size of the outer case, the front and back surfaces of which are corrugated, so as to render them flexible and elastic. The air is exhausted from this box, which is afterwards hermetically sealed. The box is firmly fixed in the case, and to its front surface one end of a broad lever is connected by a socket, whilst the other end of the lever rests upon a spiral spring, which by resisting to a certain extent the pressure of the lever, keeps the surfaces of the box in a state of tension. By means of another lever and a chain, the movements of the first lever are transferred to the hand, which indicates them upon the scale.

Ch. Do you think then that the aneroid will supersede the mercurial barometer?

Fa. Most probably not, because the small movements required to be indicated by the barometer must, to a certain extent, be interfered with by transference through a system of levers; although some careful researches by Mr. Belville, of the Royal Observatory, have shown that this result occurs to a considerably less extent than might have been anticipated.

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